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# A Systematic Review of Socio-Technical Systems in the Water–Energy–Food Nexus: Building a Framework for Infrastructure Justice

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**Abstract:** This paper explores the place of technological interventions in the conceptualisation of the Water–Energy–Food Nexus (WEF Nexus). The focus is on the just infrastructure interventions required to decarbonise and adapt to the challenges of the climate crisis for sustainable livelihoods. We explore the overlap between two bodies of work, the WEF Nexus and Socio-Technical Systems, grown from different disciplinary perspectives, to scrutinise the extent to which there is a coherent synthesis of work that can examine infrastructure impacts and trade-offs in a WEF system. Following a systematic literature review and analysis, a framework is proposed for water and energy infrastructure interventions to both support sustainable development and recognise infrastructure's role in a just and equitable society. This framework will support the creation of models that are less likely to miss vital components of a system or potential trade-offs and supports a multi-disciplinary approach to infrastructure interventions.

**Keywords:** socio-technical transitions; complex systems; infrastructure; water–energy nexus; ecosystems



**Citation:** Shrimpton, E.A.; Balta-Ozkan, N. A Systematic Review of Socio-Technical Systems in the Water–Energy–Food Nexus: Building a Framework for Infrastructure Justice. *Sustainability* **2024**, *16*, 5962. https://doi.org/10.3390/su16145962

Received: 21 June 2024
Revised: 5 July 2024
Accepted: 8 July 2024
Published: 12 July 2024



## 1. Introduction

Water and energy systems are intimately connected [1,2]. The importance of this connectivity is acutely seen through the lens of the water–energy–food nexus (WEF nexus) where life-essential water–energy interactions with land use and food production are exposed. The WEF nexus is a key component of sustainable development [3–5] and points to the interdependency of WEF systems and the unintended consequences, or lost potential benefits, in considering one system in isolation from the others [3–5]. In engaging with critical infrastructure systems for sustainable development, an inclusive systems view is required.

The critical infrastructure systems we rely upon need to decarbonise and adapt if we are to meet the challenges of the climate crisis. In reviewing those systems, seeing infrastructure as a Socio-Technical System [6] can help to ensure that a new infrastructure intervention is constructed in its social context and is acceptable and meets the needs of the communities it is designed to serve [7,8]. This is even more important in times of transformational change with new and adapted systems taking shape. Viewing these changes through both WEF and Socio-Technical System studies can offer opportunities for a fuller social and environmental systems view of impacts and opportunities.

This paper explores the literature at the interface of WEF and Socio-Technical Systems to investigate the extent these concepts have been synthesised to enhance infrastructure interventions and support the Sustainable Development Goals (SDGs), particularly SDGs 6, 7, and 9 [9]. In addition to WEF and Socio-Technical Systems, this paper includes a further issue often missing in the discourse. When bringing about transformational change, there will almost inevitably be 'winners' and 'losers'. How those that benefit and those that do not is decided is arguably a measure of our success (or otherwise) in achieving a just society.

The role of justice is therefore explored as supported by the need for both sustainability and justice in the articulation of the 'just transition' to net zero emissions [10,11].

This articulation is important if we are to meet the challenges of the climate crisis whilst ensuring context-sensitive and just infrastructure interventions [12,13]. Often, conceptualisations of social and ecological systems such as WEF neglect to integrate technology, prejudicing sustainable development [12,13]. Getting infrastructure interventions 'wrong' brings potential issues over interventions not only failing to meet community needs but even increasing vulnerabilities [14,15]. Further illustrative examples include discussions on suitable and acceptable sanitation systems [16], the factors around the siting of hydropower plants beyond technoeconomic factors [17], or over-reliance on hard infrastructure, at least in part, leading to disaster [18]. Resolving this gap will also support our work on the Management of Disaster Risk and Societal Resilience project (MADIS) (funded by the Engineering and Physical Science Research Council (EPSRC, Grant no. EP/V006592/1, UK and the Belmont Forum) under the following project title: Theory of Change Observatory on Disaster Resilience) [19], working with drought-prone small-scale farmers in developing economies. In that project, we aim to identify a range of drought indicators for coping and adaptation to drought, beyond meteorological features [20]; to include WEF systems, social context, and the impacts of infrastructure interventions, with the aim to understand trade-offs; and to support informed decision making around potential interventions.

Socio-Technical System, WEF, and justice are three lenses that can be used to evaluate the impacts and emergence of transformational infrastructure change. The aim of this paper is to explore how the learning behind these concepts can be integrated in infrastructure interventions to achieve social, environmental, and technological change 'justly'. This will be achieved through a systematic review of the literature that addresses frameworks for WEF and Socio-Technical Systems thinking, including a review of the extent to which justice is considered within those texts. This will showcase work that addresses the intersection of these concepts and will seek to synthesise the findings. The contribution to knowledge will be the resulting framework called Just Technological, Ecological and Social infrastructure Systems (JusTESS) that captures these concepts and systems around infrastructure transformations and enables the benefits of their integration to be explored. The value of this literature review will be in exploring the extent that the WEF, Socio-Technical Systems, and justice studies are integrated and exposing gaps and opportunities for synthesis. The value of the framework will be by offering a comprehensive and integrated view of infrastructure transitions within these fields, with questions and insights that account for a fuller system view to be advanced through further research.

This paper sets out the key conceptual terms in Section 2, including a discussion on some of the existing models and frameworks that may illuminate the connectivity between WEF and Socio-Technical Systems. Section 3 sets out the methodology for the systematic literature review. Section 4 sets out the results of the systematic review, which are then discussed in Section 5 along with the introduction of the JusTESS framework. This is followed by the conclusion in Section 6.

## 2. Context

Socio-Technical Systems, WEF, and justice have developed from different disciplinary backgrounds. To cater to a multi-disciplinary readership, the concepts behind these terms are summarised in this section.

Socio-Technical Systems address how the technical components of a system impact social structures and vice versa [8,21]. A body of work on Socio-Technical Systems addresses the transition to net zero, technology's role in the move to more sustainable systems, and the supportive social and governance structures that need to be in place for that to happen [22,23]. As an illustration, in many instances, it is not the lack of technology that is the barrier to change but the social acceptability of what is being proposed [23]. Socio-Technical System principles are well established and researched and help expose the complex interaction between technology and perceived and real risks, in addition to trust, governance, and stigmatisation, as well as design that is not context-sensitive. Notable examples within infrastructure include narratives around nuclear energy [24] and the domestic use of hydrogen [25,26], amongst others. Socio-Technical Systems as a body of work can help us understand the opportunities and challenges in how social and technical systems (in this case infrastructure) transform together. Understanding and working with this connectivity helps mould technology and vice versa, improving the prospects of innovation in our infrastructure systems being accepted and embedded into society [27–29].

The promotion of the WEF nexus as a concept is credited to the World Economic Forum's 2011 global risk report [30] and the subsequent Bonn conference [31]. The WEF nexus considers water–energy–food as interlinked systems, which is essential when looking at resilience in the context of increasing scarcity in resources, competition for those resources between sectors, and resource security [32,33]. WEF nexus studies often consider the interaction of these resource systems under different scenarios or in the face of change. WEF frameworks have been used, for example, to build models and support indicator selection for resilience, e.g., [34–36], or in sustainability assessments across sectors to evaluate different scenarios and resource impacts following system changes, e.g., [1,37]. WEF supports a more holistic, ecosystem view of infrastructure provision as opposed to a siloed framing of energy, water, or food production (and land use) in isolation.

When reviewing the WEF nexus, with its application in sustainability studies, a body of work known as Socio-Ecological System studies often underpins the thinking behind this concept. Socio-Ecological Systems view social and ecological systems as interconnected, co-dependent systems, often focussing on human rules, responses, and behaviours, e.g., [1]. Ostrom, and her Institutional Analysis and Development model (IAD), is a seminal actor in this area, and she has addressed the social rules and systems around natural resources and the impact they have on the sustainable use of natural resources [38,39]. Ostrom sought to dispel Hardin's 'tragedy of the commons' [40] as an inevitability and showed the complex interaction of social and ecological rules and processes that impact the sustainability of natural resources. The focus of attention and attributes of interest in Socio-Ecological Systems and Socio-Technical Systems have areas of overlap, with key differences. The physical attributes of a resource together with context and place are features of Socio-Ecological Systems that can be lacking in Socio-Technical System studies [38,41].

The Stringer framework [33] integrates a Socio-Ecological Systems approach and draws some of the WEF and Socio-Ecological Systems themes together with justice. It pays attention to policymaking impacting the WEF nexus and policy influence on resilience outcomes at different scales—local, regional, national, and global. The framework recognises that resilience and WEF have been critiqued for their lack of explicit attention to justice issues and that a system may be resilient, but outcomes may be unjust. This is addressed in the framework by the integration of justice and equitable outcomes as components. In a more recent framework by Kurian, the WEF nexus approach is visualised as a product of the interaction of environmental resources, the intersection of interests, and the distribution of risks [42]. In doing so, it tries to articulate the interactions and incentives that trigger change within the WEF nexus and bring about a transformation of the system. Whilst not referencing justice directly, it does refer to issues of poverty, equity, and trade-offs, which the WEF nexus can help bring to light.

Both the Stringer and Kurian frameworks consider governance, rules, and interests within the WEF nexus, although the role and influence of infrastructure is less clear [33,42]. Infrastructure can be viewed as a technical conduit between society and the environment, connecting people with the resources it needs [13], and a Socio-Ecological Systems approach has been criticised for failing to address the agency of technology within these processes [12,13,41]. This has led to new bodies of work that try to integrate Socio-Technical Systems and Socio-Ecological Systems, e.g., [13,41,43]. The Social Ecological and Technological Systems (SETS) work by Markolf et al., for example, considers the importance of these components together when looking at infrastructure and highlights the connectivity of the social–environmental–technical spheres by reference to disaster studies, using Hurricane Katrina as an illustration [12]. There are connections to justice within this new work in highlighting a history of inequalities and vulnerabilities resulting in exposure to the worst impacts of the hurricane, but it is acknowledged that SETS is a relatively nascent body of work still conceptual in nature and requires further development [12].

To progress to a just transition, the role of justice needs to be clearly articulated. Scholsberg's highly regarded work on environmental justice can be drawn upon, which expands upon Rawl's work on distributive justice and integrates concepts of procedural justice and respect and recognition [44–48]. The dimensions of scale and time in justice assessments should also be emphasised, as articulated, for example, in recent work around multi-scalar hydrogen justice [49] or in addressing past water distribution impacts on indigenous populations [50]. This allows past injustices and colonial impacts, along with impacts on future generations and full life-cycle management, to be expressly brought into view.

The following systematic review looks at how the current literature integrates WEF and Socio-Technical Systems, embodying the challenges of transformational infrastructure change and the extent to which justice considerations are features of that assessment. The question posed is, can a framework be developed to encapsulate the key components of a just system, with reference to water–energy infrastructure change, to form the basis of a model and indices for a just transition?

## 3. Methodology

A systematic literature review was adopted following the process utilised by Yigitcanlar et al. [51]. The following search terms were identified:

Water AND energy AND food;

AND socio tech* (* to allow for variants including technology, technical, etc.);

AND framework.

The inclusion of 'justice' was explored but resulted in too few results. The exclusion of 'framework' resulted in too broad a spectrum of results, and its inclusion helped focus on studies where WEF and Socio-Technical Systems were conceptualised.

The review process was as follows (Figure 1).

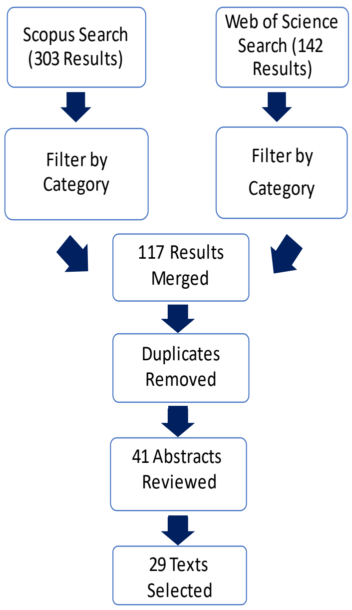


**Figure 1.** Literature review process.

The search terms were applied to the title, keywords, and abstract search in Scopus to include grey literature, resulting in 303 results. The documents were screened to exclude categories not applicable to this study, for example, 'medicine'. The process was repeated with the database Web of Science, with 142 results identified and then screened, the results merged with the Scopus results, and duplicates removed. The abstracts from the resulting 41 texts were reviewed to further eliminate studies not relevant to the search aims. Following the abstract review, 29 texts were taken forward into the study.

The publication dates of the 29 texts are shown in Figure 2. All were peer-reviewed journal articles save for two conference papers.

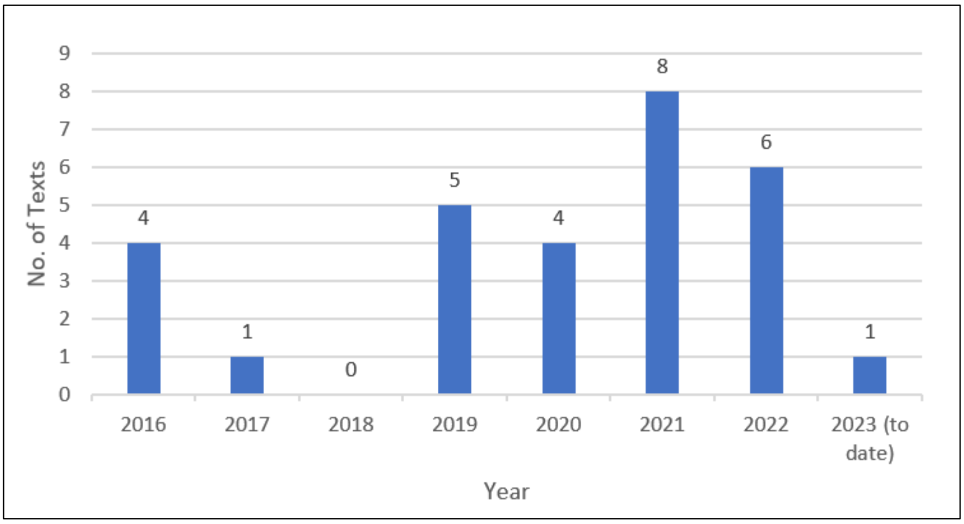


**Figure 2.** Distribution of studies over time.

Despite the common search terms, what was immediately apparent was the broad range of disciplines, scales, interests, and approaches within the texts, including qualitative critiques, e.g., [52]; bottom-up capacity building and participatory approaches, e.g., [53]; policy development and scenario analysis, e.g., [54]; and quantitative modelling for system optimisation, e.g., [55]. It was also apparent that whilst the texts touched upon aspects of the WEF nexus and Socio-Technical Systems, it was to widely differing degrees. For some texts, particularly the critiques, the content was highly relevant to the creation of a framework. For others, particularly where their purpose was to quantify W–E, E–F, and F–W linkages for a particular region, there were fewer overriding principles or insights into WEF and Socio-Technical Systems to draw upon. The range of texts is noteworthy, as it highlights the potential use, flexibility, and interest of these concepts and how they can be embraced by different disciplines. The range also highlights the potential benefits of a framework that can show how the seemingly diverse range of studies can be brought together. Rather than focus on the differences, of interest here are the areas of commonality.

In devising a framework, there are many variants and diverse ways of categorising the documents. Categorisation is useful in tracking differences within like categories and for organisation and presentation purposes, but a standard system of categorisation, such as by resource, focus, or scale, is not useful here as it either results in too many documents or too few, often with little relevant content in common. Instead, the articles are categorised through an iterative, reflective process of organising and re-organising until categories or themes helpful to answering the research question emerge, drawing upon principles of thematic analysis [56]. What was looked for were groups of studies with commonality between them in terms of the methodological approach or, where that was not possible, common subject matters or goals. The rationale behind the categorisation was to break down a seemingly disparate group of texts and aid in the comparison between similar approaches. Through this process, the categories chosen were (1) Quantitative Models, (2) Modelling and Decision Support Frameworks, (3) Participatory and Social, (4a) Drivers and Policy (Food), (4b) Drivers and Policy (Energy), (5) Disaster, and (6) Critiques.

In categorising the studies, some fell within more than one category, and where that occurred, the category most pertinent to the research issue was chosen. The categories are listed with the reviewed studies in Table 1.

**Table 1.** Categorisation of reviewed studies.

| Category | Authors | Ref. Number | Scale(s) |
|---|---|---|---|
| Quantitative Models | Enayati et al., 2021 | [57] | Waterbasin (Iran) |
| | Bai and Sarkis, 2019 | [58] | National, regional |
| | Li et al., 2021 | [59] | Regional (Corn belt, USA) |
| | Payet-Burin et al., 2019 | [60] | Waterbasin, cross-border (Zambezi River Basin) |
| | Shi et al., 2020 | [61] | Waterbasin, cross-border (Syr Darya River Basin) |
| | Yue et al., 2022 | [55] | Regional (Hubei, China) |
| Modelling and Decision Support Frameworks | Nisal et al., 2021 | [62] | Global |
| | Nisal et al., 2022 | [63] | Global |
| | Mouriatidou et al., 2016 | [64] | Global |
| | Hejazi et al., 2023 | [54] | Global, national (MENA) |
| Participatory and Social | Johnson and Karlberg, L 2017 | [53] | National (Ethiopia and Rwanda) |
| | Harmon et al., 2022 | [65] | Global, national, community, individual (SSA) |
| | Hibbett et al., 2020 | [66] | Regional, community |
| Drivers and Policy (food) | Miller, W (parts 1 and 2) 2019 | [67,68] | Community (Gold Coast, Australia) |
| | Subedi et al., 2020 | [69] | National (Nepal) |
| | Smidt et al., 2016 | [70] | Regional (High Plains, USA) |
| | Thompson et al., 2021 | [71] | Regional (Des Moines, USA) |
| | Soares Dal Poz et al., 2022 | [72] | National, regional |
| Drivers and Policy (energy) | Lefore, Closas and Schmitter, 2021 | [73] | National (MENA, SSA) |
| | Larsen et al., 2019 | [74] | Global, national, regional |
| Disaster | Daher et al., 2021 | [36] | Global |
| | Dhaubanjar et al., 2021 | [17] | Waterbasin, cross border (Indus basin) |
| | Irwin et al., 2016 | [75] | Community, individual |
| Critiques | Adom et al., 2022 | [76] | National (South Africa) |
| | Cairns and Krzywoszynska, 2016 | [52] | National (UK) |
| | Rollason et al., 2021 | [77] | Waterbasin, cross border |
| | Avraam et al., 2020 | [78] | N/A |
| | Bruns et al., 2022 | [79] | National, Community (SSA) |

Scales range from individual, community, regional (within a country), national, and global, with some across multiple scales. Waterbasin studies varied from in-country to cross-border. Some studies had a general application; others were focused or had results that were tested on a specific country or area. When a specific country or area was considered pertinent to the study, it is specified in the table in brackets. SSA refers to sub-Saharan Africa. MENA refers to Middle East North Africa.

## 4. Results

The studies were reviewed within their categories to understand how the social, ecological, and technical interlinkages were conceptualised and for justice features that could support the design of a framework. The analysis resulted in a nuanced understanding of these broad themes, with new themes emerging.

### *4.1. Quantitative Models*

In this section, studies that focus on the quantification of WEF links, as well as computer-based and mathematical models, are brought together. These studies record the results of models and indices relevant to a scenario or problem. The results of the studies themselves are not of direct interest to this study. What is of interest are concepts behind the models or the founding principles upon which the decision to select a particular category of social, technical, or ecological indicators was made.

None of the texts present a framework integrating concepts within WEF and Socio-Technical Systems, but there are features to consider. There are two broad sub-categories. The first includes optimisation models, with examples here that assess technology with agricultural or hydrological components [55,59,60]. In these studies, if a social indicator is included in the assessment, it is mostly linked to the economic implications of change, such as labour cost [55], willingness to pay [59], and production for economic optimisation [60].

The second sub-category takes a wider view of social features, for example, assessing socioeconomic security [57], accounting for stakeholder differences [58], or assessing human behaviour and impacts on ecosystem needs [61]. The Bai [58] and Shi [61] models suggest that governance, stakeholder behaviour, and values are dynamic and influential components of a WEF–Socio-Technical System. Climate scenarios and global datasets were used in the Enayati et al. study [57] on choices around new infrastructure and impacts. The components of the decision support framework in the Enayati et al. study are more difficult to interrogate, as are the findings that 'the role of the social aspect of this project, on the other hand, is practically negligible' [57]. This could be construed as suggesting social components are not relevant to their framework or just to its application in the study but would require a more detailed interrogation of the underlying data to understand this further.

Overall, with the two sub-categories, the former category arguably comprises indicators that are more readily available and more objective, although limited in focus, to optimisation and economics. The limitations of these approaches are addressed in the Critique section below. The latter category more readily aligns with Socio-Ecological Systems thinking, which embraces differing interests and values, formal and informal rules, and governance more widely as a key part of the resilience and sustainability of the system [38].

### *4.2. Modelling and Decision Support Frameworks*

The four texts in this category could be included in Section 4.1 but have been separated out for analysis because of their commonality, being framed at a higher conceptual level than most other texts and utilising global datasets, with most of the other studies focusing on national or watershed scales.

The Mouriatadou et al. study [64] modelled water–energy–land–climate systems to assess how climate change may impact energy needs and land use and, in turn, water demand. Water demand was considered under different water policy and shared socio-economic pathways [64]. Similarly, the Hejazi et al. study [54] provided a quantitative model for analysing water availability, covering energy and agricultural systems, and applied the model to assess impacts at a regional level. It used climate scenarios, water management paradigms, and socioeconomic development scenarios to predict water availability. The Hejazi results suggest water scarcity is dominated more by demand requirements (such as from power generation and agriculture) than by climate change impacts, highlighting the influence of human and social decision making on resource sustainability.

Two papers led by Nisal [62,63] address a global model for sustainability with the WEF nexus at its heart. The first study introduced the Generalised Global Sustainability Model (GGSM), and the second used the model to address policy issues. GGSM is described as a 'simplified ecological food web set in a macroeconomic framework' [62]. The model shows a production and recycling system with resources processed and consumed (noting herbivores and carnivores), with both natural, ecological and human-influenced ecological flows. The model also highlights the global resource pool that is, or can become, unusable or inaccessible and how that may increase alongside pollution and the extinction of species. The macroeconomic tool inputs ecological and economic parameters and then supply, demand, wage, and population determinants. The infrastructure itself was not described; the model is more about flows and production, albeit it is implicit that infrastructure will be a conduit for those flows.

The Mouriatdou [64] and Hejazi [54] studies include a governance and interests component with the Nisal works [62,63], taking a holistic view of the production cycle, albeit with less in terms of explicit infrastructure and governance drivers.

*4.3. Participatory and Social*

In contrast to quantification and top–down approaches, three other studies look at participatory methods.

Johnson and Karlberg address participatory scenario building [53]. There are two points from the study to take forward. Firstly, there was disagreement between stakeholders over the best use of resources, as well as acceptance that disagreement may not be resolved. The second is that whilst consensus might not be achieved, viewing issues through the WEF nexus meant an understand was possible regarding the implications of decisions and the impact these have on others. This recognises competing interests but with the potential for the nexus to promote understanding—if not agreement.

Further nuances to social engagement are noted in the Harmon et al. study on Farmer-Led Irrigation Development (FLID), noting that collective action does not necessarily mean the avoidance of social exclusion [65]. The study addresses historical water governance paradigms and contradictory Integrated Water Resource Management (IWRM) policies, showing how these have been entangled into FLID applications.

The Hibbett et al. study looked at urban food production in small and medium-sized towns [66]. It highlighted the data gap issues at this scale and sought to fill them using participatory citizen science projects. This brings benefits in data gathering but also potential improvements in social capital and social networks. A point made in the study is the potential for these networks to be used in emergencies, supplying local data and social networks to secure critical WEF lifelines and supply chains in response to emergencies.

Together, these studies note conflict between competing interests and the importance of having a voice for all. Although not always articulated in justice terms, the first two studies can be used to link justice principles to the distribution of benefits and burdens and the importance of due process with all voices being heard in relation to distributional decision making. Knowledge through data, enabling a 'voice' and flowing between people, is also viewed as an important feature of the infrastructure system, and, in this way, data collection can be viewed as an essential part of a participatory justice process [80].

*4.4. Drivers and Policy*

The studies in this category focused on governance and social policy. Most of the studies focused on food, with the remainder focussing on energy.

4.4.1. Food

Nepal is addressed in the Subedi et al. study, where food and nutrition are said to be more pressing than water availability [69]. The study looked at technological interventions and ecosystem-based adaptation, albeit with an emphasis on the latter. In their framework, biodiversity is described as 'naturally and human-modified infrastructure' [69], reflecting the wider meaning that can be given to infrastructure beyond hard, concrete systems. The promotion of nature-based solutions where possible is advocated for in the study. At the centre of their modified nexus framework are dimensions of food security flanked by environmental/natural capital on one side and social welfare income on the other. The environmental aspects include ecosystem service stocks, access to natural capital, and access to credit. Social welfare income includes employment, wealth, social and political capital, and infrastructure, although the latter is not defined and is given a relatively modest role. Within these categories, the issue of access to funds and governance are said to be significant.

Smidt et al. address physical, agricultural, and socio-economic drivers around water use in the US High Plains Aquifer, highlighting governance as a major driver behind behaviour and resource use [70]. The study provides insights into governance at different scales—for example, where governance decisions made at the national level can be sensitive to local needs. Issues over land rights and ownership and the drivers around farmer profitability were highlighted as potential policy levers. The study also notes that water use in the region is intimately connected to short-term farmer profit [70] and suggests that without governance, through policy support and incentives to address profitability, current behaviours will persist, and groundwater decline will continue.

In another developed economy—this time, Australia—socio-technical factors were assessed in two connected conference papers by Miller, examining urban development and urban food production [67,68]. In the case study, urban planning provided hard infrastructure and supported soft infrastructure to enable urban food production. For example, alongside estate-level sewage treatment and water recycling, there were legal initiatives such as covenants attached to properties relating to solar and rainwater use and social and online community portals.

Again, on urban food systems, Soares et al. sought to integrate ecological systems into urban and peri-urban environments based on the governance of common pool resources and socio-ecological systems [72]. Common features in Socio-Ecological System studies were evident, for example, 'rules in use' defining the interaction between resource and community, as well as 'place' and the social and physical setting of the community under analysis [38].

The paper by Thompson et al. addresses urban food systems in the US [71]. They included an agent-based model to integrate farmers' decisions on the type and volume of crop in response to demand, prices, and yield, etc. against different objectives, e.g., environmental protection or profit. Their research is a work in progress, and ultimately, it is said that the model will be developed to include policy, social interaction, and markets.

From these studies comes the importance of 'place' and how infrastructure systems create a space that allows for, or negates, nature and socially sensitive infrastructure. Governance is seen as a behaviour modifier, whether that be through policies, modifying funding and market-drivers, or harder legal requirements. The studies provide a means for different types of infrastructure to be considered, beyond hard infrastructure systems.

#### 4.4.2. Energy

Although energy is a feature in all studies, two have a dominant energy focus.

The first paper by Larsen et al. highlighted the close intersection between energy production and water availability [74]. It discussed the amount of water needed in many forms of electricity generation. Like the Hibbett et al. study mentioned in Section 4.3, it noted data gaps that need to be filled for the interrelationship to be understood.

Data are also touched upon by Lefore et al. in the context of missing data around marginalised communities and inequities [73]. The study examined policy in the context of sustainable, solar-powered irrigation for smallholder farmers in the MENA and SSA regions. It noted economic drivers behind the growth of solar use along with blockers and unequal access in marginalised communities, with women referred to as the 'bottom of the pyramid' with extremely low access. Economic incentives and new business models were suggested, including solar co-operatives and new forms of social organisation to wrap around the technology to support it. The unequal access to resources highlighted in the study supports the need for a distributive and procedural justice mindset when considering improvements to infrastructure systems.

### *4.5. Disaster*

Three studies expressly include disaster risk in their WEF and Socio-Technical Systems assessment, aiding a view of the system under stress.

Dhaubanjar et al., 2021, provided a systematic framework for hydropower development, which accounts for trade-offs, including WEF nexus impacts and natural hazards. Its focus is on the difference between the theoretical potential of hydropower and its actual sustainable potential when the trade-offs are considered [17]. 'Sustainable exploitable potential' is defined as the 'sustainably achievable potential accounting for known hazard risk, anthropogenic limitations and environmental constraints to sustainability' [17]. Geohazards form part of that assessment. Potential sites are either excluded if the risk is too high or are included with an additional cost for land and building stabilisation to mitigate the risk. Place is a feature linked to (potentially extreme) conflicts of interest. Many infrastructure projects may fall between jurisdictional boundaries. These jurisdictional boundaries can come with historical and current conflicts and do not necessarily match the geological or hydrological features for the best nexus approach. The potential for conflict was therefore noted, and provisions were made for it by including additional cost and risk factors. Social factors were highlighted as an area for future work, noting the desire for stakeholder engagement to identify development preferences and socio-cultural values. The study, therefore, arguably has a techno-environmental leaning, albeit highlighting social values and preferences as work for the future.

The second article, by Daher et al., addresses the interconnectivity of WEF resources and the impact of compounded shocks to those systems [36]. The study depicts the interconnectivity of hazards and the impact on the WEF nexus, with a focus on migration, pandemics, and natural disasters. In evaluating existing WEF models, the paper noted that few studies consider disruptions or, if they do, do not cater to cross-sector impacts. The resulting framework showed the impact flows between WEF systems and these three hazards. The migration framework, for example, showed the impacts of increasing migration to a region, with the consequent impact on WEF resource availability. It also showed triggers for migration away from a region due to water stress and inadequate food or energy supplies. Migration and people flows were linked to resource flows, with people flows impacting hazards, which in turn, impacts resources and vice versa.

The Irwin et al. study addresses how natural disasters can expose hidden vulnerabilities within WEF systems [75]. The study is grounded in behavioural studies and reflects on the need to address decision making in response to both environmental change and innovative technologies. The model that was used integrated triggers called 'Press and Pulse Events' as prompts around technological innovation, human adaptation, and impacts on WEF. It separates technological innovation from technological adoption in line with Socio-Technical Systems approaches (not all innovations are socially acceptable). The model incorporates 'hazards', WEF, technology, and human agency with the impacts of migration and land use change. As a study that draws upon human–nature coupling and technological adoption, it could arguably be viewed within the SETS literature.

The studies together draw upon themes of place and boundaries, conflict and values, and behaviour and flow. These are dynamic interactions with flow changes in response to a shock or disruption but can also cause a disruption to flow and services.

### 4.6. Critiques

The Avraam et al. paper is a critique of optimisation-based WEF studies (such as those analysed in Section 4.1 above; [78]). Its concern is that critical decisions on priorities and what is valued are made when one dataset is chosen over others. This leaves the potential for decisions that express results as 'optimal', but which conceal the social and political ramifications of decision making and where the competing objectives of stakeholders are not considered. This a critical point to make and highlights the limitations of some modelling and optimisation approaches in this field.

The Cairns et al. critique argues that the use of the WEF nexus in the UK is a 'buzzword' [52]. Like the Avraam study, it is concerned with the potential for WEF discourse to be biased towards technical solutions to environmental problems and technocratic forms of environmental managerialism. Power imbalance is another theme, not only in terms of vulnerable communities but across sectors, disciplines, and what is considered both 'expert' and 'knowledge'. The authors promote social science as a way of challenging some of the norms and practices that may emerge from the use of the nexus concept.

Rollason et al. examined the Socio-Ecological System and WEF models in the context of Interbasin Water Transfers (IBWTs; [77]). The critique mirrors some of the conceptual concerns raised by Cairns et al. IBWTs are noted as a technological solution rather than one that addresses social norms around water demand. From their review of the IBWT literature, concerns are raised over equity and unequal power relations, amongst other factors. Neither WEF nor Socio-Ecological System studies are considered solutions. Instead, their 'enhanced WEF Nexus' interpretation shows the links between WEF, but within each component are local, regional, and supra-regional levels to encourage the account and consideration across the nexus at different scales. This is all set within the context of governmental, environmental, societal, and economic drivers. Although infrastructure systems play a role in IBWTs as the subject matter of the study, the role of technology and infrastructure is not expressly conceptualised in their model.

Bruns et al. address nexus infrastructure with a political ecology lens [79]. It challenges the nexus when construed in a neutral, apolitical way and instead advocates for the nexus to be viewed as about resource systems and governance being political in nature and seeking to address uneven outcomes. They also address less formal infrastructure processes, or as they put it:

> '*Accordingly, nexus studies tend to have a very strong bias towards a focus on accountable flows (omitting or ignoring unaccountable flows), formal networks (neglecting the fragmented nature of infrastructure) and state provision*'. [79]

As well as informal mechanisms, they highlight historical context in understanding infrastructure systems, formal and informal, and disruptions. Disruptions are discussed in terms of the inequalities they are likely to expose, as well as the opportunities for change. They highlight low levels of agency amongst vulnerable groups, often women, limiting their ability to mitigate resource insecurities.

Adom et al. critique the application of WEF policies in South Africa, noting a lack of institutional synergies and cross-sectoral coordination [76]. Like the Harmon paper, the study raises the notion of how good intentions badly implemented can lead to inequalities, the entrenchment of poverty, and the shifting of a crisis from one sector to the other. It notes issues of the lack of awareness of the nexus concept within the population and policymakers. The study advocates for vertical and horizontal interaction oriented by grassroots realities.

Power and governance and the political nature of infrastructure and WEF decision making are a common thread in this category. The role of technology at the expense of other control mechanisms such as behavioural or nature-based options are emphasised.

## 5. Discussion

### 5.1. Themes

This section identifies the themes driven by the studies and explains the rationale for their inclusion in a framework. The suggested themes are discussed with an explanation for their inclusion. This is followed by a table where each theme can be cross-referenced with each study. The section ends with a discussion on how the themes can be viewed in a framework.

#### 5.1.1. Overview

The themes chosen were normative, representing accepted features of Socio-Technical System or WEF studies or evolved from a review of the texts and are as follows:

- Resources in an ecosystem;
- Infrastructure services;
- Influence of place;
- Governance, interests, and scale;
- Justice;
- Flows;
- Disruption and risk.

#### 5.1.2. Resources in an Ecosystem

Inevitably, in view of the search terms and focus, the connectivity between water–energy–food is a feature of all of the studies. W–E–F resources are viewed as integrated within an ecosystem rather than in sector-specific silos. This addresses the criticism of studies outside the WEF nexus that miss the impacts and opportunities from a cross-sector view [36]. Drawing upon the Nisal papers, this section should include not only resources that are utilised but also resources that are inaccessible and unusable [62,63]. With WEF, this strikes a particular note when considering processes that pollute water or intensify the desertification of land, for example, and is a useful reminder to be cognisant of what could be irretrievably lost when choosing between interventions.

#### 5.1.3. Infrastructure Services

The placing of 'infrastructure services' was evident in most but not all of the studies. That this is sometimes missing is foreseeable. As discussed in Section 2, the underpinning of many WEF studies is Socio-Ecological Systems thinking, which has, in the past, been criticised for a lack of attention to the place of technology in a Socio-Ecological System [13]. It is also possible that the lack of focus on technology in some instances reflects a purposeful desire to avoid a default towards hard technological solutions rather than softer interventions such as governance and demand management, e.g., [52,69,77,78].

A new framework offers an opportunity to advance and include technology as part of the system whilst being cognisant of these concerns. In any conceptual framework, mention of the forms of infrastructure interventions should be broadly based with the usable resources channelled through hard, soft, digital, or nature-based infrastructure and not limited to hard, traditional, engineered systems, e.g., [69]. The preference for nature-based solutions and more flexible, less rigid solutions can counter the prevailing approach of hard infrastructure engineering, which has been criticised for its inflexibility and lack of resilience, particularly to climate shocks [15,81]. At the same time, hard infrastructure has its place as a potential solution, albeit no longer as the default option but one in a range of potential propositions. This position reinforces the benefit of more engineering and social science integration to ensure that a range of solutions are considered for a context-sensitive design.

This theme also includes data in understanding infrastructure impacts and leads to the explicit inclusion of data collection as part of the infrastructure services system [66,73]. Data collection enables an understanding of the flows of services and resources around the system. Infrastructure and data are linked to other themes; for example, and as discussed below, information is an enabler for procedural justice and due process. Conversely, the lack of data can mean certain important parameters are 'invisible', inhibiting due process.

#### 5.1.4. Influence of Place

The influence of place is noted in 15 studies. It occurred across the categories, save for the Modelling and Decision Support Frameworks, which is explained by the attention mostly on global datasets in that group. The influence of place was anticipated to be significant from the Socio-Ecological Systems literature. Resources and infrastructure services are influenced by place, where people function in a given environment [38]. Place can be geological, impacting water flows; geographic, placing physical boundaries around a system; or administrative, which may not match watershed areas. Place sets a physical and administrative boundary for the system of interest but can also include context and historical influences, which can be a setting for conflict [17]. The infrastructure systems within defined boundaries influence WEF and its place or context, and, vice versa, infrastructure impacts production and its flow of resources and services.

#### 5.1.5. Governance, Interests, and Scale

In terms of the social system, the dominant feature from the studies revolved around governance, with this theme seen in 24 out of 29 studies. Governance discussions include the use of forms such as policy, economic incentives, and legal and regulatory measures, e.g., [67,82]. More than the forms of governance, however, power imbalances, competing interests, and local, national, and global scales are features discussed particularly in the

Critiques and Participatory and Social categories. What is seen is the importance of governance as a mediator between competing interests, in turn impacting behaviour.

Governance was a key feature of both the Stringer [33] and the Kurian [42] frameworks. Distinguishing between local, national, and international scales of governance was a particular feature of the Stringer framework with differing interests and degrees of power and influence, including finance and funding availability [33]. Within the Kurian framework, the inclusion of its 'intersection of interests' component was used in the explanation of behaviour, movement, and tipping points in a system [42]. Drawing these frameworks and the narratives from the studies together, the forms and tools of governance are deployed to 'moderate' between scales and mediate between competing interests, providing drivers for behaviour in the system.

#### 5.1.6. Flows

The theme of flow had examples in all categories except Critiques and Drivers and Policy. Throughout the system, there are flows of resources, people, and data. The system is in a constant state of flux. Flows can be prompted in either direction by resource abundance, depletion, or risk, the results then impacting resource availability, e.g., [36,75] The flow of WEF resources through infrastructure to society is a fundamental part of an infrastructure system. The discussions within the studies around flows, however, are more sophisticated than simply the flow of WEF resources and include, for example, human and ecological flows in the Nisal studies [62,63] and migration in the Daher study [36]. The theme of flows is evident in all three studies in the Disaster category, where flows are disrupted, system limits are exceeded, and mass flows or interruptions may be experienced, e.g., [36,62]. This can lead to an interruption of services and harm but also potential change and benefits [75]. This theme helps to highlight the fact that systems are not static.

#### 5.1.7. Disruption and Risk

Disruption and Risk is a prominent feature in the Disaster category, representing features that impact the system and put it under stress, prompting positive and negative changes to the flows of resources and people within the system. Disruption and Risk, however, extends beyond disaster and shocks. They represent the vulnerability or otherwise of the system to outages and interruptions more widely; this recognises that, in some instances, a disruption of infrastructure services is the norm [79]. Shocks can be viewed as external to the system, but following disaster management and vulnerability studies, vulnerability to the impacts of disaster and shock is also a feature of the system itself [15,83]. It is noted that the impacts of shock and disruption may be experienced differently by different groups.

#### 5.1.8. Justice

The experiences of those within the system leads to the final theme of justice. Despite the need for a 'just' transition, justice is far less prevalent than other themes, being clearly seen in only nine studies. It is noted in the Participatory and Social and the Critiques categories and is missing from Quantitative Models and Modelling and Decision Support Frameworks. That it is more prevalent in qualitative than quantitative studies may reflect perceived issues with how justice can be measured or operationalised.

Even when it is raised, there is no single coherent articulation of justice emanating from the texts. There is no systematic application of the dimensions of justice such as equitable distribution, due process, and respect and recognition. What is articulated is narrower and focusses on injustices and who, how, and where outcomes of an unjust system may be experienced, the gender experiences in the Lefore study being an example [73]. Where justice is articulated, it offers insights into how the system may be experienced, including how experiences may differ as a result of exposure to stress in the system, noting that the most vulnerable in society often have fewer resources to adapt to and cope with risk and disruption [83]. The justice component in the design of a framework could therefore be visualised in how disruption and risk is felt unevenly within the system.

#### 5.1.9. Themes and Studies

Table 2 shows which studies contain which themes.

**Table 2.** Critical analysis of reviewed studies across themes.

| Category | Authors | Resources in an Ecosystem | Infrastructure Services | Influence of Place | Governance, Interests, and Scale | Flows | Shocks | Disruption and Risk | Justice |
|---|---|---|---|---|---|---|---|---|---|
| Quantitative Models | Enayati et al., 2021 [57] | x | x | | x | | | | |
| | Bai and Sarkis, 2019 [58] | x | x | x | x | | | | |
| | Li et al., 2021 [59] | x | x | x | x | x | | | |
| | Payet-Burin et al., 2019 [60] | x | x | | | | | | |
| | Shi et al., 2020 [61] | x | | x | x | | | x | |
| | Yue et al., 2022 [55] | x | x | | | x | | | |
| Modelling and Decision Support Frameworks | Nisal et al., 2021 [62] | x | x | | x | x | | | |
| | Nisal et al., 2022 [63] | x | x | | x | x | | | |
| | Hejazi et al., 2023 [54] | x | | | x | | | | |
| | Mouriatidou et al., 2016 [64] | x | | | x | | | | |
| Participatory/Social | Johnson and Karlberg, 2017 [53] | x | | x | x | | | | x |
| | Harmon et al., 2022 [65] | x | x | | x | | | | x |
| | Hibbett et al., 2020 [66] | x | | x | x | x | | x | x |
| Drivers and Policy (food) | Miller, W (part 1 and 2) (2 documents) [67,68] | x | x | x | x | | | | |
| | Subedi et al., 2020 [69] | x | x | x | x | | x | x | |
| | Smidt et al., 2016 [70] | x | | x | x | | | | |
| | Thompson et al., 2021 [71] | x | x | x | x | | | | |
| | Soares Dal Poz et al., 2022 [72] | x | | x | x | | | | |
| Drivers and Policy (energy) | Lefore; Closas, and Schmitter, 2021 [73] | x | x | | x | | | | x |
| | Larsen et al., 2019 [74] | x | x | | x | | | | |
| Disaster | Daher et al., 2021 [36] | x | | x | | x | x | x | x |
| | Dhaubanjar et al., 2021 [17] | x | x | x | x | x | x | x | |
| | Irwin et al., 2016 [75] | x | x | x | x | x | x | x | |
| Critiques | Adom et al., 2022 [76] | x | x | | x | | | | x |
| | Cairns and Krzywoszynska, 2016 [52] | x | | | | | | | |
| | Rollason et al., 2021 [77] | x | x | | x | | | | x |
| | Avraam et al., 2020 [78] | x | | x | x | | | | x |
| | Bruns et al., 2022 [79] | x | x | | x | | | x | x |

### 5.2. Framework

Drawing the themes together, the framework shown in Figure 3 is suggested, named the JusTESS Framework (a framework for Just Technological, Ecological, and Social infrastructure Systems). The aim of the framework is to encapsulate the key components of the studies.

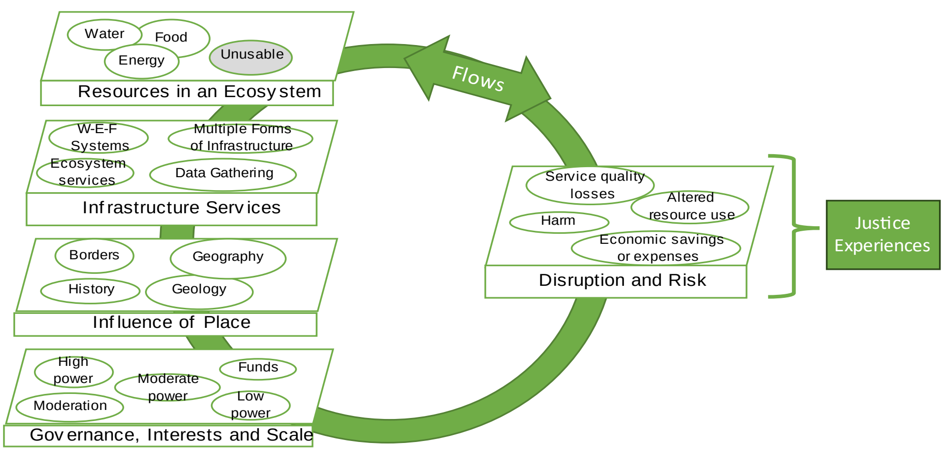


**Figure 3.** Just Technological, Ecological, and Social infrastructure Systems (JusTESS) Framework.

The framework shows the themes of Resources in an Ecosystem, Infrastructure Services, Influence of Place, and Governance Interests and Scale. Within each theme are sub-themes that are suggested by the texts and analysis. These can be reviewed and expanded upon as the framework is tested and applied.

The system is in a state of flux, indicated by flows that extend beyond WEF resources and impact all themes. Again, this stresses that systems are not static.

The Disruption and Risk component represents the outcome of the system and emphasises where justice impacts may be experienced or may be a factor in prompting a transition. The framework makes plain the role of infrastructure in context. The place of technology has been overlooked on occasions and is expressly tackled in the framework. It is also hoped that frameworks such as this will gain traction in the infrastructure engineering field to encourage a wider system and problem framing when designing solutions [82]. This is encouraged by the deliberate and express inclusion of multiple forms of infrastructure. Indeed, applying the framework is likely to require input from multiple disciplines and can act as a guide and prompt to multi-disciplinary teams working towards WEF nexus solutions.

The value here is the integrated nature of the framework. In viewing the framework, its immediate use as a prompt to critique WEF and Socio-Technical System studies is apparent—for example, testing the choice of parameters and indicators in a proposed model. It can be used to identify categories of indicators that might be overlooked, including the extent to which resources become unusable or governance is analysed at different scales and across borders. It is envisaged that the framework will support the consideration of a wider range of indicators for WEF projects, infrastructure selection, policy change, and scenario setting. The framework does not mean that all themes must be considered in every study, but it prompts their consideration and justification if they are to be omitted from a model. It is also anticipated that the components within the framework will be adapted as work on the application of the framework advances.

Most significantly, the framework provides justice as an outcome of infrastructure services, linking just (or unjust) experiences to infrastructure provision. It is this area where the most amount of work is further required. The articulation of justice within the texts is patchy and unsophisticated. This is not an exceptional finding, as a similar lack of sophistication has been noted, for example, in the literature on water infrastructure [84], and the need for justice is noted in the Stringer framework [33]. Further study is suggested to expand upon the justice component of the framework beyond the texts. Whilst the tenets of justice in terms of distribution, due process, and respect are well known, this a conceptually developing field. There is emerging work pertinent to infrastructure provision challenging Westernised views of energy justice [85], developing the role of restorative justice to remedy past injustices [49], addressing how justice concepts can be operationalised into engineering infrastructure models [86], tackling justice for non-human life [87,88], and applying the concept of a 'just transition' beyond its employment and economic roots [89,90]. The framework provides ground to help develop and operationalise justice concepts, rooting them within a WEF nexus and Socio-Technical Systems framing.

In terms of limitations and further work, what the framework does not do is profess to synthesise the vast bodies of work around Socio-Technical Systems and WEF. What it can do is provide a framework that guides the creation of questions around infrastructure transitions to support that synthesis. Further work, influenced by previous approaches (e.g., see [91]), is envisaged by reviewing the Socio-Technical Systems and WEF literature but focusing on and developing questions for each theme—for example, in drawing together bodies of work around the influence of place on technology and acceptability. This study is also somewhat limited, by its nature of a systematic literature view, to the literature identified. This has shown itself to be a particular issue with the articulation of justice where there is a significant and recognised gap [91]. Further work expanding upon the articulation of justice experiences linked to the themes is also envisaged.

## 6. Conclusions

The aim of this study was to explore the extent WEF and Socio-Technical Systems concepts had been synthesised to enhance infrastructure interventions that support the SDGs and a just transition. In the studies identified, there was no coherent synthesis. To fill the gap, a framework was developed to encapsulate the key components of the studies and to visualise the environmental, social, and technological features of the system. This has been achieved by synthesising learning from the literature at the intersection of WEF and Socio-Technical System studies, looking for what bonds the diverse range of studies.

The resulting framework can support the creation of models and the selection of indices for policy and decision making. The framework can be used to inform and evaluate policymaking. It will also enable a critique of existing infrastructure studies more widely, identifying gaps in thinking, with the overall goal of encouraging infrastructure interventions that are just, sustainable, and have a deeper and broader understanding of their social and environmental impacts. The framework can be applied to the examples referenced in the Introduction in order to prompt a wider system view of new sanitation systems and hydropower siting beyond techno-economic features, as well as potentially support interventions that are at a lower risk of inadvertently increasing vulnerabilities. For the MADIS project [19], this framework can be used to underpin and prompt the selection of a wide range of indicators to understand system impacts and drought beyond meteorological factors, for example, to explore the impacts of the introduction of energy systems for irrigation while appreciating ground water depletion—or power, political capital, influence, and access to funds—and the connection these indicators have in coping and adaptation to drought. There is also an intention to explore the use of the framework in research projects on the introduction of new hydrogen infrastructure technologies and the impacts on energy security, water use, land use change, and social acceptance in each context [92]. In doing so, issues of justice, including what is introduced and how, who benefits, and who is recognised, also come to the fore.

In short, the framework is not the last word in this area but supports ongoing developments of wider problem framing and context-sensitive and sustainable solutions. By integrating concepts of justice, it can show just (or unjust) outcomes emerging through the assessments of risk and the impacts of disruption to services. The framework can therefore be implemented to provide novel insights into the extent that social and environmentally just outcomes are considered and achieved around infrastructure change. It can identify some of the features that need to be considered when making that assessment and provides the basis for more research in this area.

This study embraces thinking from multiple disciplines and the learning that has been generated before it. Rather than continue along a single disciplinary track, it is suggested that the next nudges forward continue in this vein.

**Author Contributions:** Conceptualization, E.A.S. and N.B.-O.; methodology, E.A.S.; validation, E.A.S.; formal analysis, E.A.S. and N.B.-O.; resources, N.B.-O.; data curation, E.A.S.; writing—original draft preparation, E.A.S.; writing—review and editing, E.A.S. and, N.B.-O.; visualization, N.B.-O. and E.A.S.; project administration, N.B.-O.; funding acquisition, N.B.-O. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was funded by the Engineering and Physical Science Research Council (EPSRC, Grant no. EP/V006592/1, UK) and the Belmont Forum under the project title Theory of Change Observatory on Disaster Resilience–TOCO DR. The support is gratefully acknowledged.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data supporting this study are included within the article.

**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## References


1. Daccache, A.; Ciurana, J.S.; Rodriguez Diaz, J.A.; Knox, J.W. Water and Energy Footprint of Irrigated Agriculture in the Mediterranean Region. *Environ. Res. Lett.* **2014**, *9*, 124014. [CrossRef]
2. Khatavkar, P.; Mays, L.W. Real-Time Operation of Water-Supply Canal Systems under Limited Electrical Power and/or Water Availability. *J. Water Resour. Plan. Manag.* **2020**, *146*, 04020012. [CrossRef]
3. Mohtar, R.H. The WEF Nexus Journey. *Front. Sustain. Food Syst.* **2022**, *6*, 183. [CrossRef]
4. UN Water Water, Food and Energy | UN-Water. Available online: https://www.unwater.org/water-facts/water-food-and-energy (accessed on 8 November 2022).
5. Cansino-Loeza, B.; Munguía-López, A.d.C.; Ponce-Ortega, J.M. A Water-Energy-Food Security Nexus Framework Based on Optimal Resource Allocation. *Environ. Sci. Policy* **2022**, *133*, 1–16. [CrossRef]
6. Geels, F.W. The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860–1930). *Technol. Anal. Strateg. Manag.* **2005**, *17*, 445–476. [CrossRef]
7. Hughes, T.P. The Seamless Web: Technology, Science, Etcetera, Etcetera. *Soc. Stud. Sci.* **1986**, *16*, 281–292. [CrossRef]
8. Bolton, R.; Foxon, T.J. Infrastructure Transformation as a Socio-Technical Process—Implications for the Governance of Energy Distribution Networks in the UK. *Technol. Forecast. Soc. Chang.* **2015**, *90*, 538–550. [CrossRef]
9. United Nations. SDGs. Available online: https://sdgs.un.org/goals (accessed on 20 April 2023).
10. Smith, S. *Just Transition: A Report for the OECD*; OECD: Paris, France, 2017.
11. European Commission. The Just Transition Mechanism: Making Sure No-One Is Left Behind. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en (accessed on 12 May 2023).
12. Markolf, S.A.; Chester, M.V.; Eisenberg, D.A.; Iwaniec, D.M.; Davidson, C.I.; Zimmerman, R.; Miller, T.R.; Ruddell, B.L.; Chang, H. Interdependent Infrastructure as Linked Social, Ecological, and Technological Systems (SETSs) to Address Lock-in and Enhance Resilience. *Earths Future* **2018**, *6*, 1638–1659. [CrossRef]
13. Ahlborg, H.; Ruiz-Mercado, I.; Molander, S.; Masera, O. Bringing Technology into Social-Ecological Systems Research—Motivations for a Socio-Technical-Ecological Systems Approach. *Sustainability* **2019**, *11*, 2009. [CrossRef]
14. Pelling, M. *The Vulnerability of Cities*; Routledge: Abingdon, UK, 2012; ISBN 9781136551475.
15. Collins, A.E. , *Disaster and Development*; Routledge: Abingdon, UK, 2009.
16. van Vliet, B.J.M.; Spaargaren, G.; Oosterveer, P. Sanitation under Challenge: Contributions from the Social Sciences. *Water Policy* **2011**, *13*, 797–809. [CrossRef]
17. Dhaubanjar, S.; Lutz, A.F.; Gernaat, D.E.H.J.; Nepal, S.; Smolenaars, W.; Pradhananga, S.; Biemans, H.; Ludwig, F.; Shrestha, A.B.; Immerzeel, W.W. A Systematic Framework for the Assessment of Sustainable Hydropower Potential in a River Basin—The Case of the Upper Indus. *Sci. Total Environ.* **2021**, *786*. [CrossRef] [PubMed]
18. Daniels, R.J.; Kettl, D.F.; Kunreuther, H. *On Risk and Disaster: Lessons from Hurricane Katrina*; University of Pennsylvania Press: Philadelphia, PA, USA, 2006; ISBN 0812219597.
19. Belmont Forum MADIS. Available online: https://sites.psu.edu/belmont/ (accessed on 26 May 2023).
20. Sass, K.S.; Konak, A.; Batalini de Macedo, M.; Benso, M.R.; Shrimpton, E.; Balta-Ozkan, N.; Sarmah, T.; Mendiondo, E.M.; Jesus da Silva, G.; Câmara da Silva, P.G.; et al. Enhancing Drought Resilience and Vulnerability Assessment in Small Farms: A Global Expert Survey on Multidimensional Indicators. *Int. J. Disaster Risk Reduct.* **2024**, *110*, 104616. [CrossRef]
21. Hughes, T.P. *Networks of Power: Electrification in Western Society, 1880–1930*; The John Hopkins University Press: Baltimore, MD, USA, 1983.
22. Foxon, T.J.; Reed, M.S.; Stringer, L.C. Governing Long-Term Social-Ecological Change: What Can the Adaptive Management and Transition Management Approaches Learn from Each Other? *Environ. Policy Gov.* **2009**, *19*, 3–20. [CrossRef]
23. Loorbach, D.; Frantzeskaki, N.; Avelino, F. Sustainability Transitions Research: Transforming Science and Practice for Societal Change. *Annu. Rev. Environ. Resour.* **2017**, *42*, 599–626. [CrossRef]
24. Yang, J.; Wang, J.; Zhang, X.; Shen, C.; Shao, Z. How Social Impressions Affect Public Acceptance of Nuclear Energy: A Case Study in China. *Sustainability* **2022**, *14*, 11190. [CrossRef]
25. Lawson, A. 'We've Got No Choice': Locals Fear Life as Lab Rats in UK Hydrogen Heating Pilot. *The Guardian*, 21 November 2022.
26. Gordon, J.A.; Balta-Ozkan, N.; Nabavi, S.A. Homes of the Future: Unpacking Public Perceptions to Power the Domestic Hydrogen Transition. *Renew. Sustain. Energy Rev.* **2022**, *164*, 112481. [CrossRef]
27. Geels, F.W. Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study. *Res. Policy* **2002**, *31*, 1257–1274. [CrossRef]
28. Geels, F.W. Socio-Technical Transitions to Sustainability: A Review of Criticisms and Elaborations of the Multi-Level Perspective. *Curr. Opin. Environ. Sustain.* **2019**, *39*, 187–201. [CrossRef]
29. Goodwin, D.; Raffin, M.; Jeffrey, P.; Smith, H.M. Collaboration on Risk Management: The Governance of a Non-Potable Water Reuse Scheme in London. *J. Hydrol.* **2019**, *573*, 1087–1095. [CrossRef]
30. World Economic Forum; Marsh & McLennan Companies; Swiss Reinsurance Company; Wharton Center for Risk Management; University of Pennsylvania; Zurich Financial Services. Global Risks 2011 Sixth Edition An Initiative of the Risk Response Network. 2011. Available online: https://www3.weforum.org/docs/WEF_Global_Risks_Report_2011.pdf (accessed on 8 November 2022).

31. Stockholm Environment Institute. Background Paper for the Bonn 2011 Nexus Conference: The Water, Energy and Food Security Nexus. 2011. Available online: https://www.sei.org/publications/understanding-the-nexus/ (accessed on 8 November 2022).
32. Al-Saidi, M.; Elagib, N.A. Towards Understanding the Integrative Approach of the Water, Energy and Food Nexus. *Sci. Total Environ.* **2017**, *574*, 1131–1139. [CrossRef] [PubMed]
33. Stringer, L.; Quinn, C.; Berman, R.; Le, H.; Msuya, F.; Orchard, S.; Pezzuti, J. *Combining Nexus and Resilience Thinking in a Novel Framework to Enable More Equitable and Just Outcomes*; The University of Leeds: Leeds, UK, 2014.
34. Manuel Núñez-López, J.; Cansino-Loeza, B.; Sánchez-Zarco, X.G.; Ponce-Ortega, J.M. Involving Resilience in Assessment of the Water-Energy-Food Nexus for Arid and Semiarid Regions Graphical Abstract. *Clean. Technol. Environ. Policy* **2022**, *24*, 1681–1693. [CrossRef]
35. Dargin, J.; Berk, A.; Mostafavi, A. Assessment of Household-Level Food-Energy-Water Nexus Vulnerability during Disasters. *Sustain. Cities Soc.* **2020**, *62*, 102366. [CrossRef]
36. Daher, B.; Hamie, S.; Pappas, K.; Nahidul Karim, M.; Thomas, T. Toward Resilient Water-Energy-Food Systems under Shocks: Understanding the Impact of Migration, Pandemics, and Natural Disasters. *Sustainability* **2021**, *13*, 9402. [CrossRef]
37. Ding, K.; Gilligan, J.M.; Hornberger, G.M. Avoiding "Day-Zero": A Testbed for Evaluating Integrated Food-Energy-Water Management in Cape Town, South Africa. In Proceedings of the 2019 Winter Simulation Conference (WSC), National Harbor, MD, USA, 8–11 December 2019.
38. Ostrom, E. Background on the Institutional Analysis and Development Framework. *Policy Stud. J.* **2011**, *39*, 7–27. [CrossRef]
39. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*; Cambridge University Press: Cambridge, UK, 1990.
40. Hardin, G. The Tragedy of the Commons. *Science* **1968**, *162*, 1243–1248. [CrossRef] [PubMed]
41. Smith, A.; Stirling, A. The Politics of Social-Ecological Resilience and Sustainable Socio-Technical Transitions. *Ecol. Soc.* **2010**, *15*, 11. [CrossRef]
42. Kurian, M. The Water-Energy-Food Nexus: Trade-Offs, Thresholds and Transdisciplinary Approaches to Sustainable Development. *Environ. Sci. Policy* **2017**, *68*, 97–106. [CrossRef]
43. Grabowski, Z.J.; Matsler, A.M.; Thiel, C.; McPhillips, L.; Hum, R.; Bradshaw, A.; Miller, T.; Redman, C. Infrastructures as Socio-Eco-Technical Systems: Five Considerations for Interdisciplinary Dialogue. *J. Infrastruct. Syst.* **2017**, *23*, 02517002. [CrossRef]
44. Schlosberg, D. *Defining Environmental Justice: Theories, Movements, and Nature/David Schlosberg*; Oxford University Press: Oxford, UK, 2007.
45. Schlosberg, D. Climate Justice and Capabilities: A Framework for Adaptation Policy. *Ethics Int. Aff.* **2012**, *26*, 445–461. [CrossRef]
46. Schlosberg, D. Ecological Reflexivity, Engagement, and Institutions: Implementing Environmental and Ecological Justice. In *Defining Environmental Justice*; Oxford University Press: Oxford, UK, 2007; ISBN 9780199286294.
47. Rawls, J. Justice as Fairness: Political Not Metaphysical. *Philos. Public Aff.* **1985**, *14*, 223–251.
48. Rawls, J. *A Theory of Justice, Revised edition*; Oxford University Press: Oxford, UK, 1999.
49. Müller, F.; Tunn, J.; Kalt, T. Hydrogen Justice. *Environ. Res. Lett.* **2022**, *17*, 115006. [CrossRef]
50. Neal, M.J.; Lukasiewicz, A.; Syme, G.J. Why Justice Matters in Water Governance: Some Ideas for a 'Water Justice Framework'. *Water Policy* **2014**, *16*, 1–18. [CrossRef]
51. Yigitcanlar, T.; Desouza, K.C.; Butler, L.; Roozkhosh, F. Contributions and Risks of Artificial Intelligence (AI) in Building Smarter Cities: Insights from a Systematic Review of the Literature. *Energies* **2020**, *13*, 1473. [CrossRef]
52. Cairns, R.; Krzywoszynska, A. Anatomy of a Buzzword: The Emergence of 'the Water-Energy-Food Nexus' in UK Natural Resource Debates. *Environ. Sci. Policy* **2016**, *64*, 164–170. [CrossRef]
53. Johnson, O.W.; Karlberg, L. Co-Exploring the Water-Energy-Food Nexus: Facilitating Dialogue through Participatory Scenario Building. *Front. Environ. Sci.* **2017**, *5*, 24. [CrossRef]
54. Hejazi, M.; Santos Da Silva, S.R.; Miralles-Wilhelm, F.; Kim, S.; Kyle, P.; Liu, Y.; Vernon, C.; Delgado, A.; Edmonds, J.; Clarke, L. Impacts of Water Scarcity on Agricultural Production and Electricity Generation in the Middle East and North Africa. *Front. Environ. Sci.* **2023**, *11*, 1082930. [CrossRef]
55. Yue, Q.; Guo, P.; Wu, H.; Wang, Y.; Zhang, C. Towards Sustainable Circular Agriculture: An Integrated Optimization Framework for Crop-Livestock-Biogas-Crop Recycling System Management under Uncertainty. *Agric. Syst.* **2022**, *196*, 103347. [CrossRef]
56. Braun, V.; Clark, V. *Successful Qualitative Research*; Sage: Los Angeles, CA, USA, 2013.
57. Enayati, M.; Bozorg-Haddad, O.; Fallah-Mehdipour, E.; Zolghadr-Asli, B.; Chu, X. A Robust Multiple-Objective Decision-Making Paradigm Based on the Water–Energy–Food Security Nexus under Changing Climate Uncertainties. *Sci. Rep.* **2021**, *11*, 20927. [CrossRef]
58. Bai, C.G.; Sarkis, J. The Water, Energy, Food and Sustainability Nexus Decision Environment: A Multistakeholder Transdisciplinary Approach. *IEEE Trans. Eng. Manag.* **2022**, *69*, 656–670. [CrossRef]
59. Li, S.; Cai, X.; Emaminejad, S.A.; Juneja, A.; Niroula, S.; Oh, S.; Wallington, K.; Cusick, R.D.; Gramig, B.M.; John, S.; et al. Developing an Integrated Technology-Environment-Economics Model to Simulate Food-Energy-Water Systems in Corn Belt Watersheds. *Environ. Model. Softw.* **2021**, *143*, 105083. [CrossRef]
60. Payet-Burin, R.; Kromann, M.; Pereira-Cardenal, S.; Marc Strzepek, K.; Bauer-Gottwein, P. WHAT-IF: An Open-Source Decision Support Tool for Water Infrastructure Investment Planning within the Water-Energy-Food-Climate Nexus. *Hydrol. Earth Syst. Sci.* **2019**, *23*, 4129–4152. [CrossRef]

61. Shi, H.; Luo, G.; Zheng, H.; Chen, C.; Bai, J.; Liu, T.; Ochege, F.U.; De Maeyer, P. Coupling the Water-Energy-Food-Ecology Nexus into a Bayesian Network for Water Resources Analysis and Management in the Syr Darya River Basin. *J. Hydrol.* **2020**, *581*, 124387. [CrossRef]
62. Nisal, A.; Diwekar, U.; Hanumante, N.; Shastri, Y.; Cabezas, H. Integrated Model for Food-Energy-Water (FEW) Nexus to Study Global Sustainability: The Main Generalized Global Sustainability Model (GGSM). *PLoS ONE* **2022**, *17*, e0267403. [CrossRef] [PubMed]
63. Nisal, A.; Diwekar, U.; Hanumante, N.; Shastri, Y.; Cabezas, H.; Rico Ramirez, V.; Rodríguez-González, P.T. Evaluation of Global Techno-Socio-Economic Policies for the FEW Nexus with an Optimal Control Based Approach. *Front. Sustain.* **2022**, *3*, 948443. [CrossRef]
64. Mouratiadou, I.; Biewald, A.; Pehl, M.; Bonsch, M.; Baumstark, L.; Klein, D.; Popp, A.; Luderer, G.; Kriegler, E. The Impact of Climate Change Mitigation on Water Demand for Energy and Food: An Integrated Analysis Based on the Shared Socioeconomic Pathways. *Environ. Sci. Policy* **2016**, *64*, 48–58. [CrossRef]
65. Harmon, G.; Jepson, W.; Lefore, N. Farmer-Led Irrigation Development in Sub-Saharan Africa. *Wiley Interdiscip. Rev. Water* **2023**, *10*, e1631. [CrossRef]
66. Hibbett, E.; Rushforth, R.R.; Roberts, E.; Ryan, S.M.; Pfeiffer, K.; Bloom, N.E.; Ruddell, B.L. Citizen-Led Community Innovation for Food Energy Water Nexus Resilience. *Front. Environ. Sci.* **2020**, *8*, 571614. [CrossRef]
67. Miller, W. Food, Water, Energy, Waste: An Examination of Socio-Technical Issues for Urban Prosumers—Part 1 (Context). *Energy Procedia* **2019**, *161*, 360–367. [CrossRef]
68. Miller, W. Food, Water, Energy, Waste: An Examination of Socio-Technical Issues for Urban Prosumers: Part 2 (Results and Discussion). *Energy Procedia* **2019**, *161*, 368–375. [CrossRef]
69. Subedi, R.; Karki, M.; Panday, D. Food System and Water Energy Biodiversity Nexus in Nepal: A Review. *Agronomy* **2020**, *10*, 1129. [CrossRef]
70. Smidt, S.J.; Haacker, E.M.K.; Kendall, A.D.; Deines, J.M.; Pei, L.; Cotterman, K.A.; Li, H.; Liu, X.; Basso, B.; Hyndman, D.W. Complex Water Management in Modern Agriculture: Trends in the Water-Energy-Food Nexus over the High Plains Aquifer. *Sci. Total Environ.* **2016**, *566–567*, 988–1001. [CrossRef] [PubMed]
71. Thompson, J.; Ganapathysubramanian, B.; Chen, W.; Dorneich, M.; Gassman, P.; Krejci, C.; Liebman, M.; Nair, A.; Passe, U.; Schwab, N.; et al. Iowa Urban FEWS: Integrating Social and Biophysical Models for Exploration of Urban Food, Energy, and Water Systems. *Front. Big Data* **2021**, *4*, 662186. [CrossRef] [PubMed]
72. Soares Dal Poz, M.E.; de Arruda Ignácio, P.S.; Azevedo, A.; Francisco, E.C.; Piolli, A.L.; Gheorghiu da Silva, G.; Pereira Ribeiro, T. Food, Energy and Water Nexus: An Urban Living Laboratory Development for Sustainable Systems Transition. *Sustainability* **2022**, *14*, 7163. [CrossRef]
73. Lefore, N.; Closas, A.; Schmitter, P. Solar for All: A Framework to Deliver Inclusive and Environmentally Sustainable Solar Irrigation for Smallholder Agriculture. *Energy Policy* **2021**, *154*, 112313. [CrossRef]
74. Larsen, M.A.D.; Petrovic, S.; Engström, R.E.; Drews, M.; Liersch, S.; Karlsson, K.B.; Howells, M. Challenges of Data Availability: Analysing the Water-Energy Nexus in Electricity Generation. *Energy Strategy Rev.* **2019**, *26*, 100426. [CrossRef]
75. Irwin, E.; Campbell, J.; Wilson, R.; Faggian, A.; Moore, R.; Irwin, N. Human Adaptations in Food, Energy, and Water Systems. *J. Environ. Stud. Sci.* **2016**, *6*, 127–139. [CrossRef]
76. Adom, R.K.; Simatele, M.D.; Reid, M. Addressing the Challenges of Water-Energy-Food Nexus Programme in the Context of Sustainable Development and Climate Change in South Africa. *J. Water Clim. Chang.* **2022**, *13*, 2761–2779. [CrossRef]
77. Rollason, E.; Sinha, P.; Bracken, L.J. Interbasin Water Transfer in a Changing World: A New Conceptual Model. *Prog. Phys. Geogr.* **2022**, *46*, 371–397. [CrossRef]
78. Avraam, C.; Zhang, Y.; Sankaranarayanan, S.; Zaitchik, B.; Moynihan, E.; Juturu, P.; Neff, R.; Siddiqui, S. Optimization-Based Systems Modeling for the Food-Energy-Water Nexus. *Curr. Sustain./Renew. Energy Rep.* **2021**, *8*, 4–16. [CrossRef]
79. Bruns, A.; Meisch, S.; Ahmed, A.; Meissner, R.; Romero-Lankao, P. Nexus Disrupted: Lived Realities and the Water-Energy-Food Nexus from an Infrastructure Perspective. *Geoforum* **2022**, *133*, 79–88. [CrossRef]
80. Shrimpton, E.A. Governance and Infrastructure in the Water Sector: Towards Successful and Just Interventions. Ph.D. Thesis, University of Birmingham, Birmingham, UK, 2023.
81. Smith, K. *Environmental Hazards: Assessing Risk and Reducing Disaster*, 6th ed.; Routledge: Abingdon, UK, 2013.
82. Shrimpton, E.A.; Hunt, D.V.L.; Rogers, C.D.F. A Governance Framework for Implementation of Scientific and Engineering Innovation in Buried Infrastructure Systems. *Front. Sustain. Cities* **2022**, *4*, 765577. [CrossRef]
83. Adger, W.N. Vulnerability. *Glob. Environ. Chang.* **2006**, *16*, 268–281. [CrossRef]
84. Shrimpton, E.A.; Hunt, D.; Rogers, C.D.F. Justice in (English) Water Infrastructure: A Systematic Review. *Sustainability* **2021**, *13*, 3363. [CrossRef]
85. Sovacool, B.K.; Burke, M.; Baker, L.; Kotikalapudi, C.K.; Wlokas, H. New Frontiers and Conceptual Frameworks for Energy Justice. *Energy Policy* **2017**, *105*, 677–691. [CrossRef]
86. Goforth, T.; Levin, T.; Nock, D. Incorporating Energy Justice and Equity into Power System Models: A Review of Current Practices and Paths Forward. *SSRN Electron. J.* **2023**. [CrossRef]
87. Celermajer, D.; Schlosberg, D.; Rickards, L.; Stewart-Harawira, M.; Thaler, M.; Tschakert, P.; Verlie, B.; Winter, C. Multispecies Justice: Theories, Challenges, and a Research Agenda for Environmental Politics. *Environ. Polit.* **2021**, *30*, 119–140. [CrossRef]

88. Kaljonen, M.; Kortetmäki, T.; Tribaldos, T.; Huttunen, S.; Karttunen, K.; Maluf, R.S.; Niemi, J.; Saarinen, M.; Salminen, J.; Vaalavuo, M.; et al. Justice in Transitions: Widening Considerations of Justice in Dietary Transition. *Environ. Innov. Soc. Transit.* **2021**, *40*, 474–485. [CrossRef]
89. Heffron, R.J.; Mccauley, D. Critical Review What Is the "Just Transition"? *Geoforum* **2017**, *88*, 74–77. [CrossRef]
90. Williams, S.; Doyon, A. The Energy Futures Lab: A Case Study of Justice in Energy Transitions. *Environ. Innov. Soc. Transit.* **2020**, *37*, 290–301. [CrossRef]
91. Williams, S.; Doyon, A. Justice in Energy Transitions. *Environ. Innov. Soc. Transit.* **2019**, *31*, 144–153. [CrossRef]
92. HyPT. Available online: https://www.cranfield.ac.uk/Research%20projects/HyPT (accessed on 10 June 2024).

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2024-07-12



Shrimpton EA, Balta-Ozkan N. (2024) A systematic review of socio-technical systems in the Water–Energy–Food Nexus: building a framework for infrastructure justice. Sustainability, Volume 16, Issue 14, July 2024, Article number 5962

https://doi.org/10.3390/su16145962