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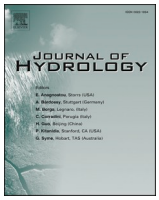

Review papers

Hidden gems: Highlighting underrepresented but valuable knowledge in the water-energy-food nexus

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ABSTRACT

What can we learn from undercited scholars in the water, energy, food (WEF) nexus literature? Do these works vary from the most commonly cited scholarship? Using a reverse citation systematic review method, the authors find a set of 78 novel yet undercited papers (<5 citations) in the food, water, energy nexus literature from lesser represented perspectives and various geographic origins that enhance current understandings around the nexus. Through text analysis, we compared the abstracts of undercited works to the most highly-cited WEF nexus articles and found that these articles shared similar language and themes. We also found several differences in how some of the most common words were used. Our results also show a higher geographic diversity of authors within the undercited works compared to highly cited. This methodological approach and our research findings have important implications for default search engine structure and scholarly visibility, both of which are important to carefully contemplate as we work to both promote a more inclusive academic enterprise and strive to make advances toward sustainable management of food, water, and energy systems.

1. Background and purpose

Within the hydrology community, there has been an increasing recognition that connection across food, energy, and water (WEF) systems should play an important role in study and management of our natural resources (Endo et al., 2020, 2017; Grady et al., 2019; Jalilov et al., 2016; Smajgl et al., 2016). Several previous reviews have highlighted strengths and weaknesses of integrating these very different systems within the nexus (Albrecht et al., 2018; D'Odorico et al., 2018; Endo et al., 2017; Leck et al., 2015). These reviews have highlighted the over representation of quantitative modeling approaches (Albrecht et al., 2018; Endo et al., 2017). They have also called for increased use of participatory approaches that work with stakeholders, policy-makers, or decision-makers across the nexus (Albrecht et al., 2018). To date, however, WEF nexus communities have encountered significant barriers to progress (Endo et al., 2020; Leck et al., 2015). Thus, there is a continual need to derive new perspectives on WEF research to create meaningful momentum and responses to global environmental challenges.

Marginalized academic researchers, many WEF nexus scholars included, also face systemic barriers to progress due to all types of biases and obstacles (Ghiasi et al., 2015; Griffin, 2020; Kelly et al., 2017; Lisnic et al., 2019). These biases and inequalities permeate scholarly discourse, as evident through several studies that have used citation analyses to understand scientific progress and research performance. For example, one study of over 670,000 engineering articles published between 2008 and 2013 found that while women engineers tend to publish their work in journals with higher Impact Factors than their male counterparts, they still receive WEFer citations, and thus less recognition, from the broader community (Ghiasi et al., 2015). Likewise, across multiple disciplines, a study of over 5 million research papers found that all articles with women in preeminent author positions have WEFer citations than those of men in the same author order (Larivière et al., 2013). Even after accounting for the impact factor of the journal and career stage of

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the author, numerous other articles have also found gender discrepancies between citation metrics across disciplines (Caplar et al., 2017; Dion et al., 2018; Ferber and Brün, 2011; Fulvio et al., 2021; Maliniak et al., 2013). Beyond gender, non-white scholars are also widely underrepresented across editorial positions, citation rates, and publication rates in multiple disciplines (Chakravartty et al., 2018; Ginther et al., 2018). While multiple systematic changes are necessary to remove these obstacles and inequalities, one step towards broadening discourse is to first recognize, learn from, and cite underrepresented scholarship.

There are two underlying assertions driving our review. First, we assert that we can learn something from undercited studies on the WEF nexus. Second, our systematic reverse-citation analysis contributes meaningful insights into citation biases across the scientific enterprise. This method also provides a way to elevate undercited scholarship without assuming the gender or racial identity of scholars. Together, this work offers a glimpse at methodological approaches for systematic reviews seeking to capture work less often represented in academic discourse. This research systematically studies undercited work in the WEF nexus to recognize less represented scholars and broaden knowledge in the nexus research community.

2. Methods

2.1. Database generation and categorical analysis

Our goal of this study was to focus on developing understandings around the WEF nexus from marginalized scholarship. However, because we did not want to assume the gender or racial identity of any scholars with whom we did not know personally, we chose to develop a reverse citation analysis approach to systematic reviews of underrepresented works in the WEF nexus. This work builds off prior scholarship by describing systematic citation biases for marginalized scholars, although all authors in our sample may not come from marginalized communities.

We created our database by including all publications that were returned from a keyword search across the Web of Science and SCOPUS databases (Fig. 1). Keyword search terms were chosen if they returned a reasonable number of search results (Supplemental Table S1) and publications that appeared primarily relevant to WEF nexus frameworks upon inspection. We downloaded database outputs from the selected search terms for all articles that had under 5 citations according to the citation count in the search databases Web of Science and SCOPUS at the time of download. After identification, duplicates were removed by matching titles and DOIs of the two database outputs. All team members participated in screening the initial article set (n = 880) manually through reading abstracts. During screening, we removed articles published after 2020 (n = 453) because they did not have adequate time to become cited. We also removed articles that were not from peer reviewed journals (i.e. book sections, conference papers, editorials, and opinions) (n = 189). In addition, we screened out articles that were not in English or did not actually relate to WEF nexus scholarship. After screening, we proceeded to code the remaining articles (n = 202)

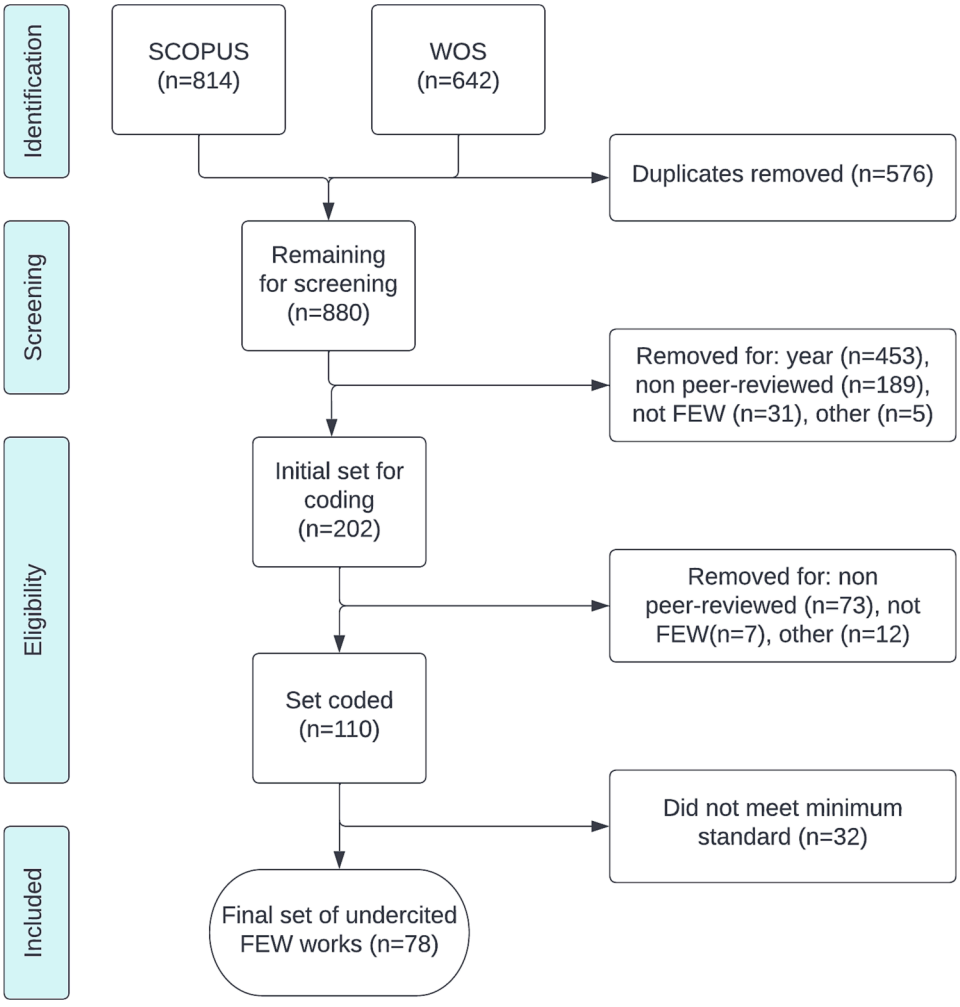

Fig. 1. Overview of selection process for systematic review.Caption: Diagram showcases identification, screening, eligibility, and final results of selection process for systematic review.

through a Qualtrics response form (Supplemental Section 1.1). During the coding process, another 92 articles were removed for not meeting the inclusion criteria. After the completion of the coding process, the author team recognized that some of the works which were coded did not meet a minimum publishable standard, thus we decided to remove 32 additional articles from our final set for analysis. To determine the minimum publishable standard, each team member evaluated the article on two questions: Does the article have a clearly articulated research question(s)? Does the article articulate clear methods to answer that research question? If the team could not identify a formal research question of any type or could not identify clear methods to answer that question, the article was excluded from further analysis. In the event there was uncertainty about a particular article, we circulated the article among multiple team members to make a collective decision about inclusion or exclusion.

2.2. Data analysis

We used three techniques to conduct our review (Fig. 2). The first two techniques involved automated comparison between our set of undercited works and a set of the most highly cited scholarship derived from the Web of Science and SCOPUS databases with the same keywords and the same number of articles (n = 78). The set of most cited articles also went through the same identification, screening, and eligibility steps to create the final list of articles. We removed all duplicates and ensured that the years of search aligned with the undercited works. Of the most cited dataset, we did not remove any due to being non-peer reviewed since all of the articles we collected from this search were peer-reviewed. Additionally, once identification, screening, and eligibility steps generated a most cited dataset of roughly 300 articles, we sorted them by highest citation and retained only the 78 most highly cited so that the two datasets were equal size. To analyze the content of both highly cited and undercited works, we leveraged the natural language processing toolkit (NLTK) in Python (Bird et al., 2009; Dennis and Grady, 2022) to compare word frequencies and examine similarities and differences between highly cited and least-cited articles (Supplemental Information Section 1.2). For our second set of analyses and hypotheses, we compared author location between highly cited and least-cited articles (Supplemental Information Section 1.2). Lastly, we manually coded the final set of undercited WEF nexus scholarship using a Qualtrics form (Supplemental Section 1.1) to descriptively analyze the details of these works. Both datasets for the most cited and undercited articles are attached as supplemental excel files.

3. Results

Our results indicate several main findings (Fig. 3).

3.1. Content analysis

We found word frequencies between the least-cited and most-cited articles to be highly similar. Of the top 50 most frequently used words between both groups, 30 words were the same (Fig. 4). Within the top 15 words, 11 words were identical. In an effort to further understand these words, we broadly categorized the words based on assumed use in the article across the themes of framework, justification, policy, research, scale, and general words. Across these themes, both the highly cited and the least-cited articles leveraged the same words to justify much of their work, describe their research, and identify components of their WEF framework. Across the theme scale, the most-cited articles frequently used country and global words within their abstracts while the most frequent least-cited words related to scale included local, community, population, and area. The only scale word that was common across both the most- and least-cited abstracts was the word region.

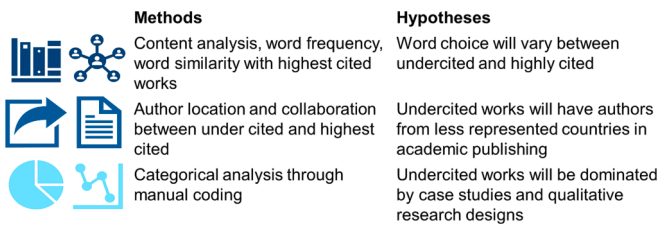

Fig. 2. Three phase analysis overview. Caption: Diagram of three phases for analyzing the systematic review.

Beyond word frequencies, we investigated both the similarity and concordance commands in NLTK to better understand the ways in which these words are used, either similarly or differently, in each body of abstracts for several key words. The word 'system' revealed similar use by both sets of articles across several aspects of WEFs including 'water', 'food', and 'nexus'. Separately, however, within the least-cited articles, the word 'system' was also used in similar contexts to words including 'sustainable', 'user', and 'clewf (climate-land-energy-water-food)'. Across the most-cited article abstracts, 'integrated' and 'resource' were also used in a similar context for the word 'system'. When investigating the words that share the same context as the word 'resource' across both sets, the words 'energy' and 'nexus' were both shared. The least-cited articles also used the words 'policy', 'scarcity', 'consumption', and 'market' in a similar context to 'resource,' perhaps implying a focus on managed energy resources. The most-cited abstracts also leveraged 'resource' in a similar context to one managed resource word ('institution') and the words 'availability', 'worsens', and 'quality,' possibly inferring an interest in both quantity and quality of resources. One word that was used in different contexts across both sets was the word 'development'. Here we found the words including 'food', 'agriculture', 'commercial', and 'international' to be leveraged in a similar way within the least-cited abstracts. In the most-cited abstracts the word 'development' was used in a similar context as 'management' and 'resilient'. We interpret this to mean that the least-cited articles are concerned with agricultural system advancement when regarding development whereas the most-cited articles may be leveraging the word development in the context of development planning and resilient built environments. Overall, we can infer several context-based findings from our natural language processing analysis. First, we interpret that the frequency analysis implies that abstract word choices are highly similar across both sets of articles. Second, the word similarity analysis did showcase that several of these words were used in both similar and distinct ways. Using the same language in different contexts has the potential to challenge a more fluid link between scholarship areas.

3.2. Authorship location and collaboration

To investigate the difference between the most cited and undercited articles in space, we plot the number of authors per country in both datasets (Fig. 5). We use author affiliation address (provided by Scopus) to get the country of each author's institution. Our results show that undercited authors represented a more diverse geographical distribution than the most-cited articles in the WEF nexus literature (Fig. 5). This aligns with previous research that has found geographic and nationalistic biases impact citation patterns (Gomez et al., 2022; Pasterkamp et al., 2007). As expected, United States of America, China, Australia, and countries in Western Europe have the largest share of authors in both data sets. However, authors from countries in Africa, South America and South Asia are more represented in the undercited work. We also found that the most-cited articles had a larger range and higher average number of authors per article than the least-cited articles (Supplemental Fig. S1) which suggests a lower level of collaboration in undercited articles. To understand the nature of international collaborations, we further investigated whether these collaborations were occurring between countries with high research productivity, between countries with low research productivity, or between countries with

Findings	Method	Implications
Abstract word frequencies align between most-cited and least-cited works yet words are sometimes used in different contexts		While word frequencies are not remarkably different, new themes emerge based on context of words between both sets of articles
There is more geographic diversity of authorship in underrepresented works		Recognition of undercited works can broaden geographic diversity in scholarship
Undercited works have fewer coauthors on average		Coauthor numbers and types may influence citation counts in future
Undercited works include more case studies		Case study research is critical to provide local context to FEW research
Undercited scholars do engage with policy analysis and recommendations		FEW nexus research continues to see importance of policy connections

Fig. 3. Summary of main findings, the methods utilized to derive findings, and implications.

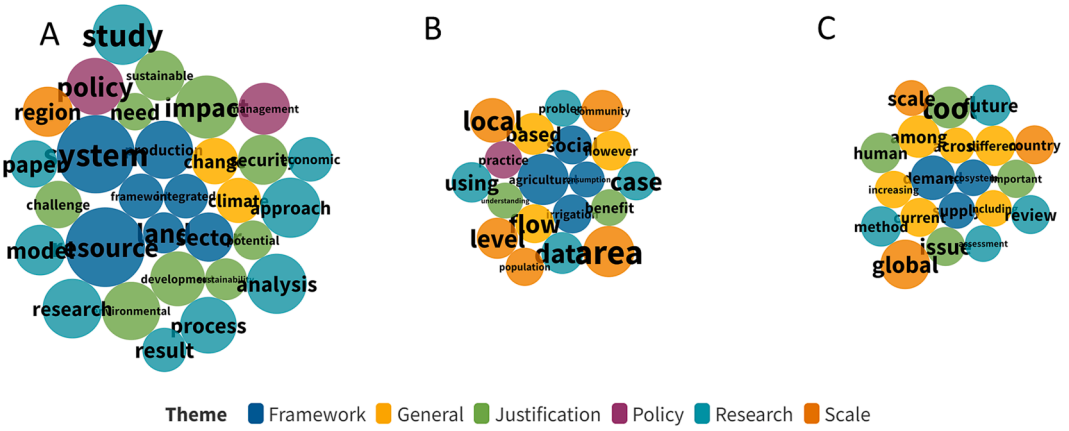

Fig. 4. Most frequent words for both sets (A), least-cited (B), and most-cited (C) articles.Caption: Panels show shared word frequencies (A) and unique word frequencies for least-cited (B) and most-cited (C) articles. Size of circle represents proportional frequency, color is associated with six themes.

high and low research productivity. We use the Springer Nature index database which ranks countries and territories by research output (Springer, 2022) to assess the level of research productivity by country. We deemed the top 10 countries in terms of research productivity according to the Nature Index as high research productivity countries for this study. We found the most highly cited authors had more international collaborations on average (Supplemental Fig. S2) and those collaborations consisted of collaboration between high to high research productivity countries about 30% of the time compared to about 10% of the time in the undercited works (Supplemental Fig. S2).

3.3. Categorical analysis: reflections on the undercited

Our undercited articles spanned multiple types of study and approach (Fig. 6). We found that the diversity of timescales of analysis is increasing over time (Fig. 6A), as is engagement with non-academics (Fig. 6C). Case study articles were quite prevalent within our article set (62%, or 49 articles, contained at least 1 case study) confirming our initial hypothesis that case-based work would be less likely to be cited. By confirming this hypothesis, our results seem to affirm that scholars across multiple fields unnecessarily devalue case study approaches when compared to studies that leverage generalizable methods such as randomized controlled trials (Hyett et al., 2014; Tight, 2010). Most of the articles included empirical data collection of some type (Fig. 6B), and many engaged with stakeholders outside of academia and provided policy recommendations within their work (Fig. 6C, 6D). The geographic extent and spatial scale at which a WEF system was investigated was diverse across these works (Fig. 6E). While the United States and China still dominated the countries studied within the undercited works, there were 50 different countries represented across the 78 articles (Supplemental Fig. S4).

Beyond descriptive summaries, we found several noteworthy articles

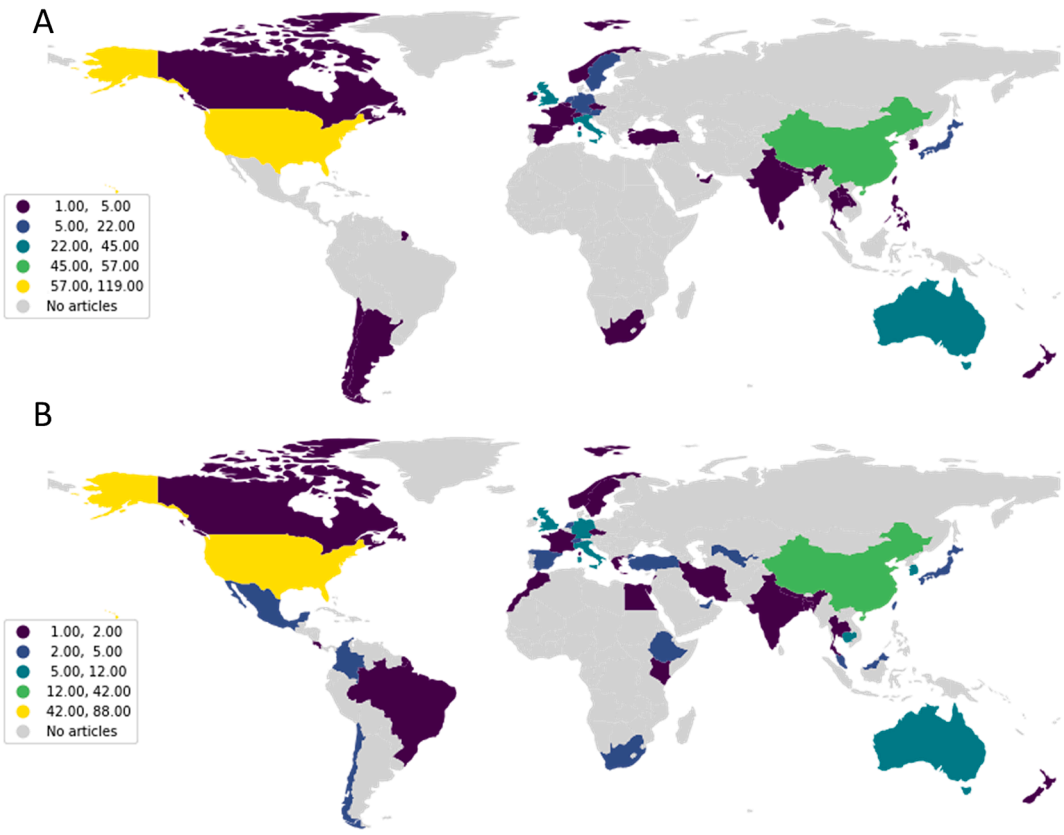

Fig. 5. Geographic distribution of authors between most-cited (A) and least-cited (B) articles.Caption: Geographic distribution of (A) most-cited and (B) least-cited articles originating from authors affiliation by country. This analysis includes all authors with affiliations listed in WOS and SCOPUS.

which captured our curiosity or taught us something new about the WEF nexus. Hanna (2020) presented a detailed analysis and review of how political economic drivers in the Middle East and North Africa relate to challenges studied in the WEF nexus such as virtual water trade (Hanna, 2020). In doing so, the author highlights gaps between scientific understanding around virtual water trade and WEF nexus research with realities driving development behavior of both state and non-state actors in the region (Hanna, 2020). Kshetry and Varshney (2017) presented a network science definition of a foodshed and showcased differences across comparisons between the United States and India (Kshetry and Varshney, 2017). Another interesting work integrated qualitative and quantitative research by conducting interviews, workshops, seminars, and other avenues of communication to inform a systems dynamic model (González-Rosell et al., 2020). In Uzbekistan, one study showed how both policy and technical improvements could be made to garner water and energy savings without compromising agricultural yields (Djumaboev et al., 2019). Within the agricultural tools, another work from our undercited studies conducted a comprehensive economic and environmental WEF analysis of an agricultural tool for wheat production. The case study provides valuable information for agricultural management and promotes the need for policy initiatives for such technologies (Fabiani et al., 2020). Across the American West, one study in Colorado used rich ethnographic, qualitative data to show the ways in which wealthy, non-local, often new, energy producers distort and control water markets impacting stakeholders water access and restricting actors abilities to generate solutions to issues through water transfer markets (Malin and MacIlroy, 2019). Finally, Hibbett et al. (2020) highlighted a broader array of stakeholders that are often missed from discussions around WEF nexus community participation and interactions (Hibbett et al., 2020). While not exhaustive, these examples highlight the depth and breadth of the work throughout our undercited studies showcasing many topics and areas of interest to WEF nexus scholars.

4. Discussion and limitation

4.1. Discussion and implications

In comparing our results to existing comprehensive WEFs reviews we can articulate several similarities. One review of 245 journal articles found that three-quarters of their reviewed works included quantitative modeling approaches while one-quarter leveraged some social science methods and one-fifth used a combination of quantitative and qualitative approaches (Albrecht et al., 2018). Our undercited works followed a similar breakdown though had slightly more qualitative and conceptual papers (30%) as opposed to quantitative (50%) (Supplemental Fig. S3). We also found that 20% of our studies included both qualitative and quantitative methods. This further implies similarity across commonly cited and undercited works (Supplemental Fig. S3). Another important outcome relating to scale of study that has been highlighted by previous reviews is the uncertainty associated with large system scales (Zhang et al., 2018). When studying global scale WEF nexus challenges, data resolution, uncertainty, and assumptions have the potential to create results that may not adequately represent reality (Zhang et al., 2018). The implications of our research show that undercited works could be valuable sources of local and regional information from real world, smaller case studies. Case study research has long been undervalued due to the lack of generalizability based on research design, yet there are still many important outcomes that can be gleaned from these works.

Another interesting trend we observed with the undercited works was that most of these works were not available in an open access format. In the majority of cases, we could access the articles via our intuitional libraries access licenses. However, we had to request interlibrary loans for 9 of our 78 article set. Although this cannot be proven

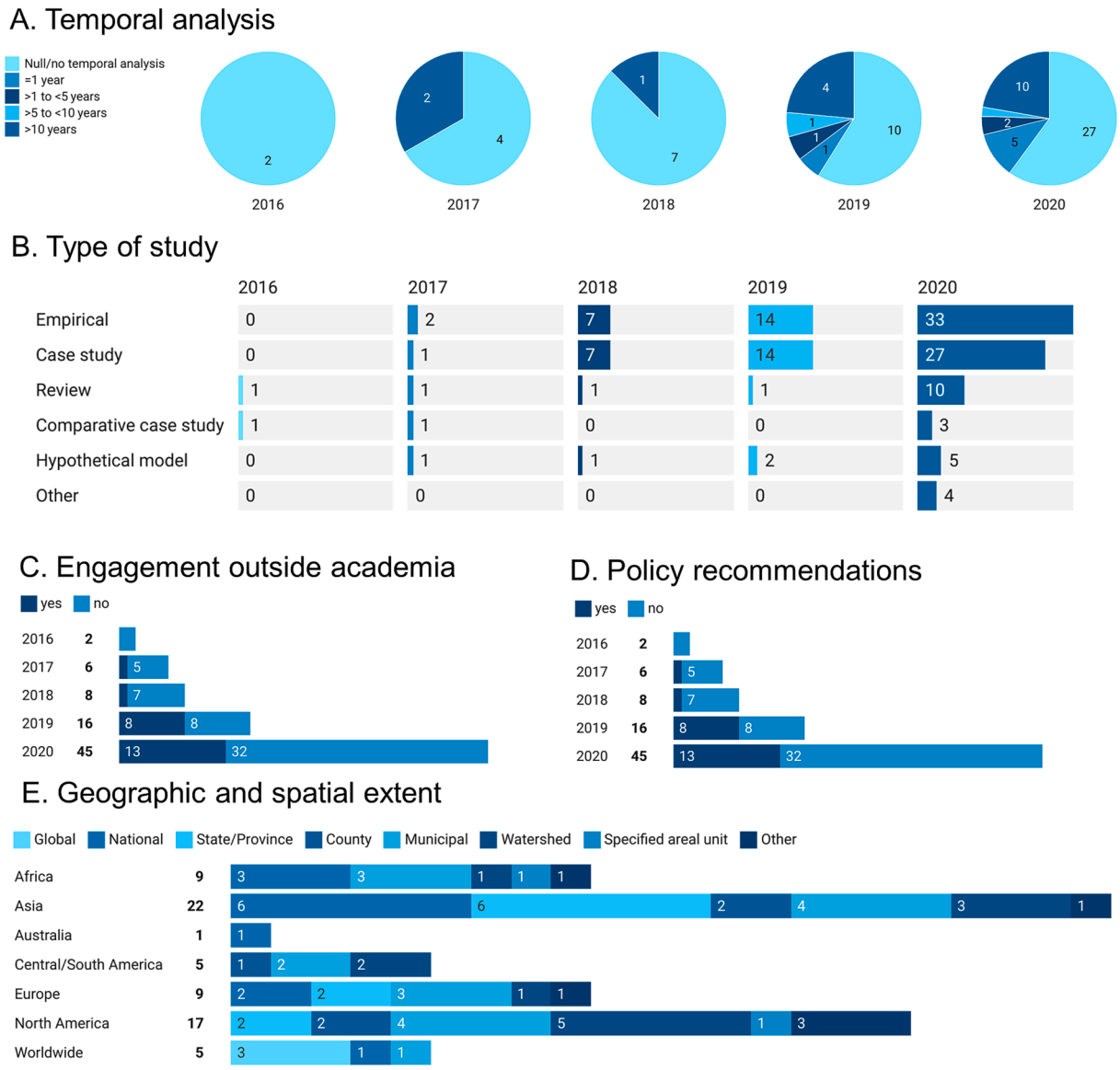

Fig. 6. Overview of content analysis results for undercited works. Caption: Panel A shows temporal periods of analysis across articles and years, Panel B shows the type of study. Note- a study could be coded with more than one type. Panel C and D represent responses to whether or not the article engaged with stakeholders outside of academia (C) or provided policy recommendations (D). Panel E summarizes the spatial extent and location of the study.

based on this study, we hypothesize that one reason some of these works are undercited is because they are held behind a paywall and, in the case of those in which we had to request loans to access them, published in journals that do not have broad subscriptions from our specific Research 1 designated university. The cost of publishing open access costs and the ethics of publishing behind paywalls continues to highlight biases and limitations in the scientific enterprise (Racimo et al., 2022; Van Noorden, 2013).

Scholars from multiple disciplines have proposed potential steps to redress citation bias in scientific literature by requiring authors to include a Citation Diversity Statement in a manuscript submitted for publication (Dworkin et al., 2020; Ray et al., 2022; Rowson et al., 2021; Zurn et al., 2020). Such statements, depending on depth and form, could certainly position authors to reflect on how their choice of citations relates to challenges of citation and other related biases (Ray et al., 2022). They do however present several practical and ethical issues that ought to be considered before requiring adoption (Ray et al., 2022). Beyond such statements, we argue within this paper that starting with the process of reviewing and learning from undercited works can move academic research in the direction of confronting these biases that perpetuate structural barriers to women and people of color in research.

4.2. Limitation

As with all research scholarship, there are limitations to our approach. First, we chose an arbitrary cutoff of 5 citations to group our undercited dataset. This citation count took place when the articles were downloaded in May 2022 and several of these articles have since received more than five citations. Second, we chose not to double-code each article, which is considered a stronger practice in systematic reviews, for two reasons. First, we believed the effort and time tradeoff it would take to double code each article was not justified with the pace at which we hoped to complete this project. Additionally, as a lab that is focused on WEF nexus scholarship, we felt that our existing expertise allowed us to individually code each article without necessary secondary coding and reconciling processes. We also limited our review to include only printed in English which is a limitation in the broader scientific knowledge community since a substantial portion of

scholarship is written in other languages. Another avenue for future work to further unlock learning from this approach could be to follow the "citation trees" of both the undercited and highly cited works. In doing so, we could understand more details about whether multiple studies are citing the same WEF articles because they are all leveraging each other's citation lists further entrenching the highly cited papers. Likewise, we might have more insight on if the undercited works would have been considered out of scope for more highly cited articles.

4.3. Personal reflections

Stepping into our own agency, we as authors found several significant outcomes related to personal reflections about this review process. First, we found that there were about 30% (n = 32) of our initial set of undercited works that were not up to what our team considered minimum publishable standard, and that could be a clear reason why these articles were not cited. This leads us to conclude that while our approach on reverse citation analysis is meant to unlock new insights from marginalized works, quality control measures are important to ensure that the work considered meets minimum standards for reproducible research and peer review in order to add to the discourse.

This process also allowed us to reflect on technological forcing that, unless an individual is attuned to pay attention to, may continue to perpetuate under representation in citations and scholarly recognition. Specifically, the way that search engine results are sorted by default in a variety of academic search engines continues to prioritize citations alongside relevance to keywords. Through this process, we have derived the assertion that in order to broaden reading, scholarship, and citations, real consideration and effort must be made to find and cite works that do not often come across our commonly returned search results.

5. Conclusion

It has long been recognized that biases are present in higher education and academic research (Ghiasi et al., 2015; Griffin, 2020; Kelly et al., 2017). Studies have shown unequal distribution of research funding, hiring decisions, search committee challenges, and citation biases among others. Women and people of color often bear the brunt of these inequities. One way to bridge these inequities is to cite and recognize the work of marginalized scholars. Despite these understandings, we do not often take time to reflect on what we can learn from missing works in the academic discourse. In this review, we set out to undertake a review of water, energy, food nexus research in a way that centralized how undercited works differ from highly cited articles. We collected, analyzed, and learned from underrepresented works in the food, water, energy nexus by doing a reverse-citation systematic review. Our work found that although these works have lower citations, they use similar words to describe the work and they use similar methods to deploy their work. Differences include geographical distribution of authors, number of coauthors, and type of author-to-author collaboration.

CRediT authorship contribution statement

Caitlin Grady: Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Sarah Torhan:** Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Lauren Dennis:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – review & editing. **Michael Gomez:** Software, Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Selena Hinojos:** Formal analysis, Investigation, Writing – reviewing & editing. **Paniz Mohammadpour:** Formal analysis, Investigation, Writing – reviewing & editing. **Luis Delgado:** Formal analysis, Investigation, Writing – reviewing & editing

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.

Data availability

I have shared all associated data and code as supplemental attachments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhydrol.2023.129597.

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