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Review

Temporal Understanding of the Water–Energy Nexus: A Literature Review

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Abstract: Guaranteeing reliable access to water and clean energy has been one of the most debated topics to promote sustainable development, which has made the Water–Energy Nexus (WEN) a relevant field of study. However, despite much development of the WEN, there are still many gaps to be addressed. One of these gaps is the understanding of temporal features. To address this, this study aimed to identify, categorize, and analyze the main temporal features applied in WEN studies based on a review of academic publications from 2010 to 2021. The results showed that most of the recent literature has focused on understanding the WEN from a quantitative perspective, often does not provide clear motivations for their choice of time, and lacks understanding of the role of historical processes. To improve the temporal understanding in WEN research, there is a need to include more methodological diversity, enhance the understanding of historical developments, and diversify the data use. The presented measures provide a chance to improve the evaluation of key issues, enhance the understanding of drivers of trade-offs between the water and energy sectors, and ground the discussion besides quantification. Moreover, these measures help the scientific community better communicate results to a broader audience.

Keywords: water–energy nexus; energy systems; water resources; sustainable development

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1. Introduction

Over the past few decades, water safety and reliable and clean energy worldwide have been some of the most debated topics to promote a sustainable society. This is mainly due to high levels of water and energy insecurity, as almost 10% of the global population still lacks electricity access [1], nearly 3 billion people do not have access to clean cooking energy [1], over 2 billion people live in high water stress areas [2], and 4 billion are exposed to severe water scarcity at least one month every year [2]. Factors such as population growth [3], increase in resource demand (e.g., water, energy, land, and food) [4–6], intensification of climate change impacts [7], and disruptive events such as the COVID-19 pandemic [8,9] further fuel this discussion and reinforce the need for urgent actions in the water and energy sector.

Despite the prominence of these issues on political agendas, much still needs to be done regarding the management of water and energy resources. As a counterproposal to business as usual, the search for new solutions moved from a sectoral perspective to a more integrative one [10], out of which the Water–Energy Nexus (WEN) arose in connection to the Bonn Nexus Conference in 2011 [11]. In short, WEN is concerned about understanding and managing the relationship between water and energy. This relationship is commonly divided into the water for energy and energy for water, as summarized in Figure 1.

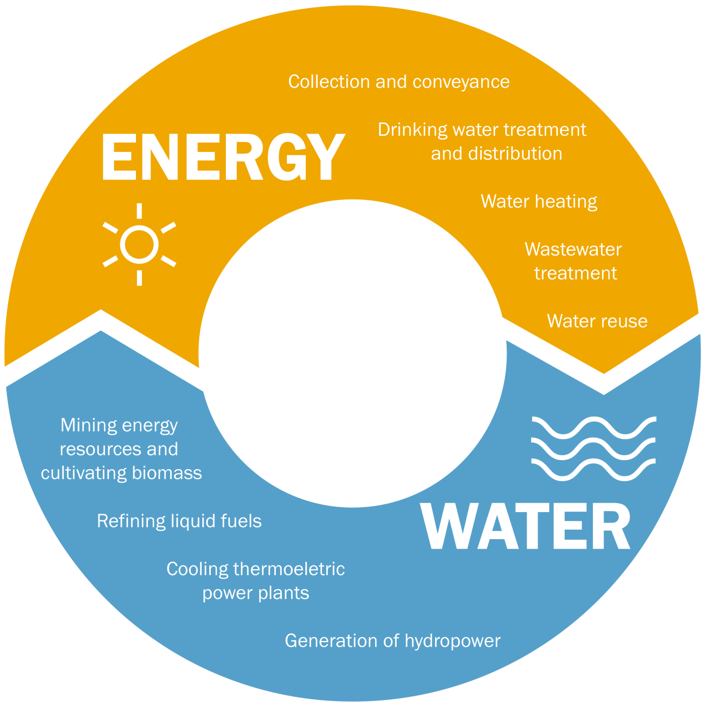

Figure 1. Key examples of interactions between water and energy systems. Adapted from Ref. [12].

Due to the management potential that the WEN brings, it has become a topic of wide interest both inside and outside academia [11]. Practical problems, such as optimizing water or energy consumption in the resource chains, drive the debate on new technological solutions [13,14]—for instance, the development of desalination technologies in water-stressed areas [15]. Geographically, WEN studies spread from city-level [16,17] to a global perspective [18,19] and can address both industrial challenges [20] and domestic water and energy supply [21,22]. In addition, current issues such as sectoral conflicts, natural resources crisis [23], and political changes [24] motivate an investigation of how these resources are connected in specific areas. Previous reviews have found that some of the most used methodologies focus on accounting, life cycle assessment, economics and econometric models, case studies, multivariate statistics, and optimization [25]. As a result, there have been calls for development of structuralized WEN approaches that support the exploration of new methodologies [26], tools [27], and conceptual frameworks.

Several recent studies have pointed out that a neglected, yet important component of WEN research is the temporal understanding [28–30]. Hamiche et al. [28] argue that the static nature seen in most studies undermines a long-term understanding of the relationship between the sectors and that improvements to capture long-term trends are essential. Dai et al. [29] indicate that the lack of historical analysis prevents a better WEN understanding, and Dalla Fontana et al. [30] emphasize that the current resource scarcity used as motivation in several studies does not address the historical background adequately.

The lack of a better understanding of the temporal features in the WEN also perpetuates and reinforces historical models [29]. A common problem here is that the current understanding of temporal features mainly focuses on changes in natural resources, resource demands, and technological choices and developments, reinforcing a technocratic view of this nexus [28–30]. Consequently, there is a lack of attention to societal and political processes over time [29,30]. Therefore, improvements in the temporal understanding will affect priorities of current WEN approaches by clarifying the role of past events and relationships. In addition, this will provide an opportunity to diversify views about the WEN.

Based on the need for a better temporal understanding of the WEN, this study aims to identify, categorize, and analyze the main temporal features in the recent academic literature on the WEN, covering the period between 2010 and 2021. This is the period after the Bonn Nexus Conference and embraces most of the literature on the WEN. Here, we define temporal understanding broader than previous articles [28–30], by including the motivation behind selection of study periods and constraints in the temporal analysis. We argue that an improved temporal understanding is essential to understand the dynamic nature of the WEN. In addition, we highlight that the most basic temporal features can point to new directions for WEN studies.

The remainder of the article is structured as follows: Section 2 presents the applied methodology by presenting the main conceptual framework and the key temporal features. Section 3 presents the key points and patterns of the main temporal features from the literature review. Section 4 presents the identified gaps and recommended steps to improve the temporal understanding of the WEN. Section 5 presents the conclusions.

2. Materials and Methods

Information about temporal perspectives in the WEN was gathered through an integrative and systematic review [31,32] of peer-reviewed academic articles. Using the Elsevier Platform, peer-reviewed articles were selected from 2010 to 2021, which encompasses more than 75% of all articles published on this topic. All steps in the literature review are presented in Figure 2. In short, the steps are the creation of the initial sample (Step 1), filtration based on exclusion and inclusion criteria (Step 2), and content screening (Step 3). In the first step, search terms were applied on articles' title, abstract, or keywords with either direct associations to the topic, such as Water–Energy Nexus and Energy–Water Nexus, or more indirect, such as water for energy and energy for water.

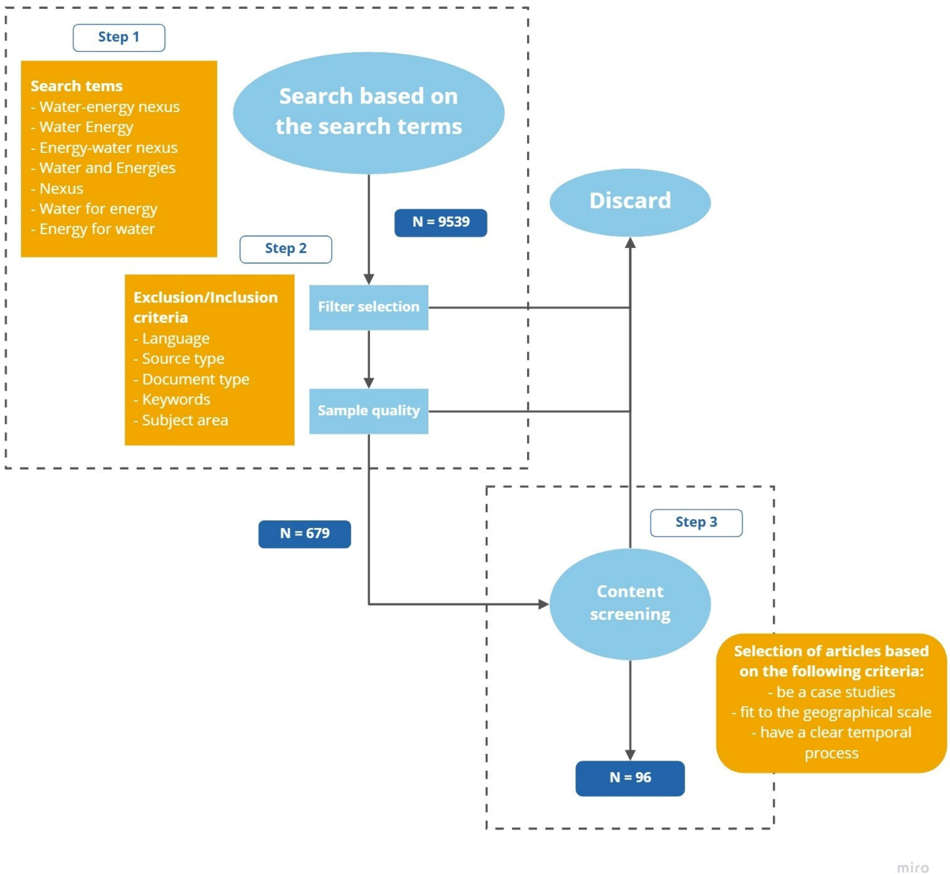

Figure 2. Literature review procedure.

This procedure resulted in 9539 (20 October 2021) articles, which, in the second step turn, were filtered using inclusion and exclusion criteria. In summary, the criteria encompassed keywords, language, source type, document type, subject area, and sample quality (full description in Appendix A). Sample quality was assessed through whether the journals had impact factors and if digital versions were accessible. This process rendered a sample of 679 articles.

In the third, we conducted a content screening on the title and abstract to restrict the sample to case studies that included a clear temporal processes and a geographical scale from city-level or larger. This excluded articles that focused exclusively on technological development (e.g., desalination membrane development [33]) or did not include any links to specific points in time. (e.g., [34,35]). This resulted in a final sample of 96 articles.

To evaluate the temporal features in the final sample, the conceptual framework presented in Figure 3 was applied. The focus of this framework was to systematize crucial aspects of the temporal understanding in recent WEN studies and to identify gaps for recommendations.

1. **Temporal extension.** Articles were distinguished based on whether they analyzed a single event in time or a period. A single event concentrates on a fixed point in time, such as a drought that occurs in a specific year. In contrast, an analysis of a period focuses on how the relationship between resources changes over time, such as meeting climate agreements. The analysis of a period can also be used to explore the future by looking for the best options to increase synergies and reduce trade-offs between water and energy.
2. **Temporal position.** Articles were categorized as addressing either past events, future events, or both. Studies of past events can seek explanations and new insights, for instance, by analyzing influential political changes or resources crises. Studies of future events can evaluate current trajectories or guide further actions, for example by exploring differences due to the introduction of new policies, technological shifts, or climate change impacts.
3. **Temporal motivation.** The motivation behind selecting the studied time in the articles was categorized as either arbitrary or determined. Arbitrary time is when the studied time was not explicitly motivated, such as articles that focused on methodologies or up-to-date analysis. Determined motivation denotes articles that had a stated motivation for studying the specified time, which can be defined as either temporal triggers or temporal targets. Temporal triggers describe past events that motivated an in-depth analysis of its effects on the WEN, such as changes in policies, environmental impacts, or economic and social crises. The temporal target is when there is a specific future target for the WEN, around which articles evaluate plans or build scenarios, such as planned infrastructure changes, policies, or climate projections.
4. **Type of research.** The predominance of quantification has been indicated as an issue in WEN studies [29,30,36]. To address this, a distinction was made based on whether articles had a quantitative, qualitative, or hybrid approach. To simplify the difference between these three approaches, we defined a quantitative approach as articles that relied exclusively on collecting and analyzing numerical data on the interconnections of nexus components. In contrast, qualitative approaches focus on collecting and analyzing non-numerical data, such as policy documents and interviews with stakeholders. Articles that share both characteristics were defined as having a hybrid approach.
5. **Temporal detail of data.** The detail of data used regarding temporal features was assessed through the temporal extension of the data and whether results were presented in the short term (<5 years), medium term (5–10 years), or long term (>10 years). When commented on in the article, data availability, data quality, and the link between type of research and data usage were also assessed.

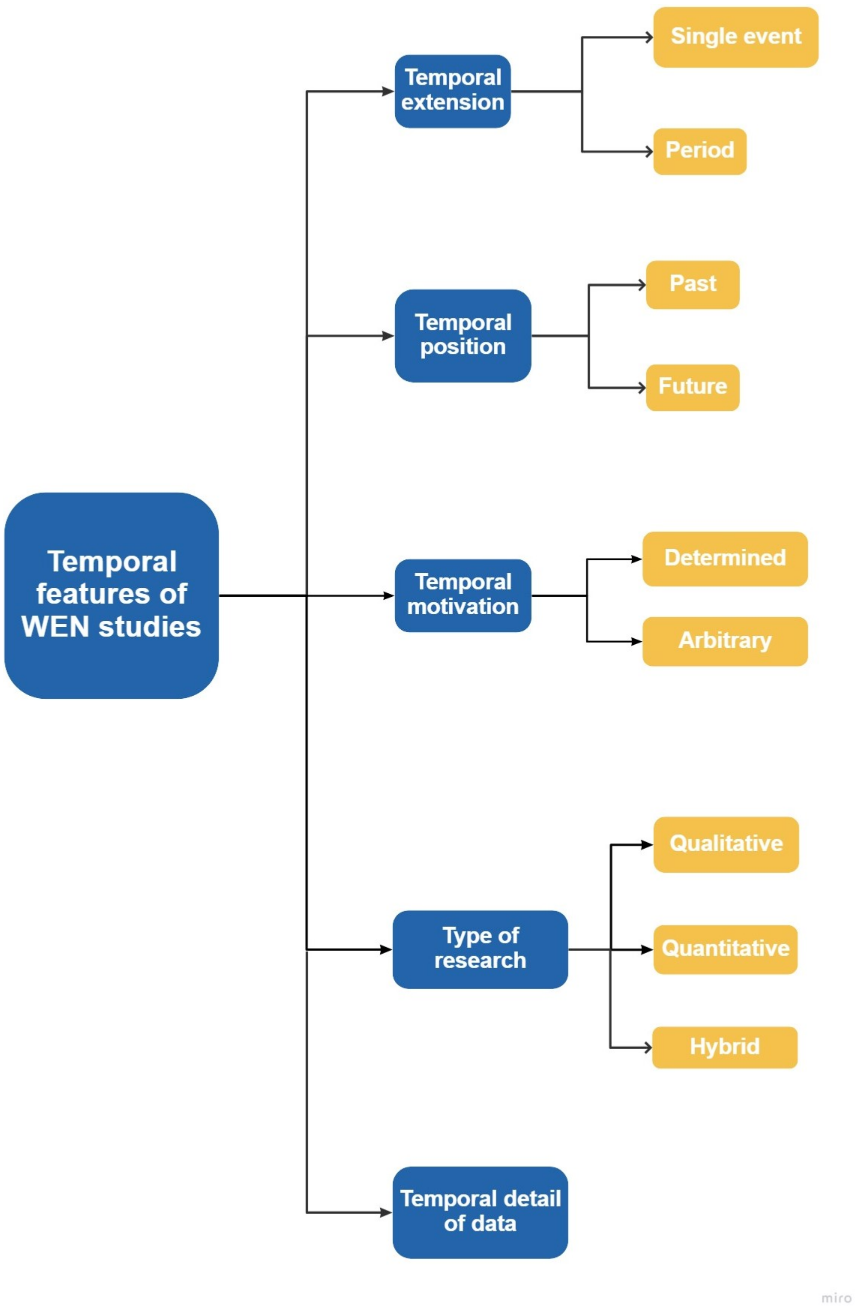

Figure 3. Conceptual framework applied to analyze the temporal features of WEN studies.

3. Results and Discussion

The following subsections present and discuss the main findings from the literature review based on the conceptual framework, including key connections between the applied categories.

3.1. Temporal Extension and Position

Figure 4 summarizes the temporal extension, temporal position, and temporal motivation of the reviewed articles.

It shows that 31% of the articles focused on single events, out of which 93% analyzed past events. Common objectives in this group of articles were to understand the most updated situation, test new methodologies, or scrutinize critical temporal milestones. The temporal positions of studies of single events are presented in more detail in Figure 5, which shows that most single events focused on events within ten years from the year of publication (green and yellow). This indicates that studies of single events are oriented towards understanding the current situation or the recent past of the WEN.

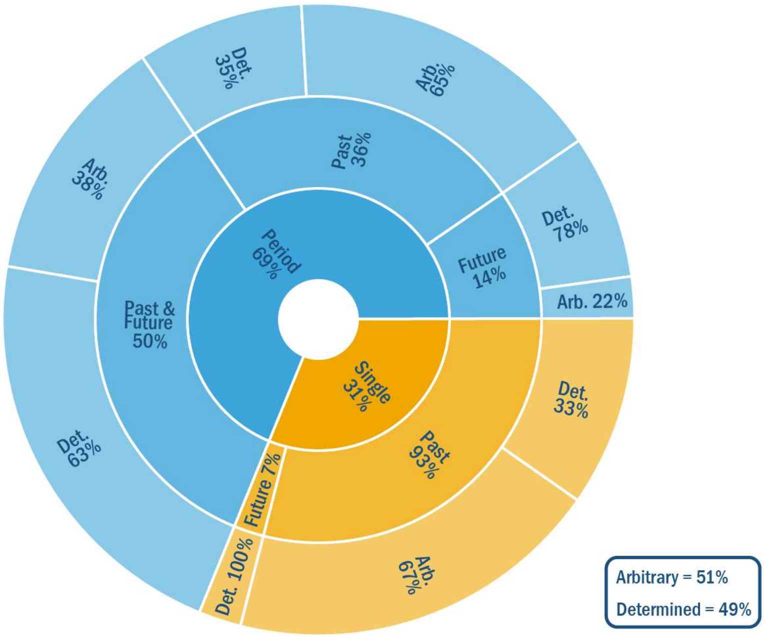

Figure 4. Summary of the temporal extension (period, single), position (past, future, past and future), and motivation (arbitrary, determined) of the selected 96 articles. The box in the figure indicates the percentage of arbitrary and determined studies in the total sample.

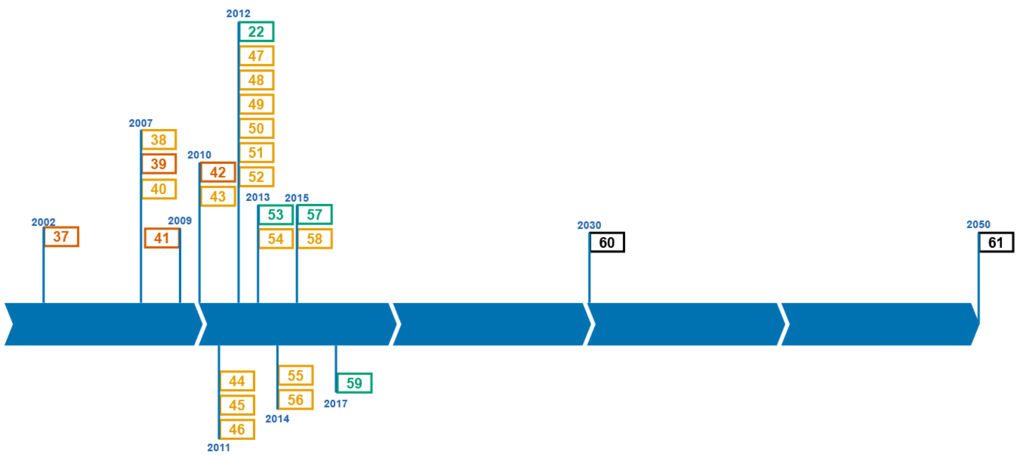

Figure 5. Distribution of temporal position in studies of single events [37–61].

As an exception to single events analyzing past events, Wang et al. [61] and Fan et al. [60] (black in Figure 5) focused on future single events. Wang et al. [61] evaluated the water-related impacts of the energy sector for the Chinese energy mix in 2050, motivated by matching the analysis with the Chinese long-term energy planning, while Fan et al. [60] quantified the effects of water and climate policies on the WEN in China in 2030.

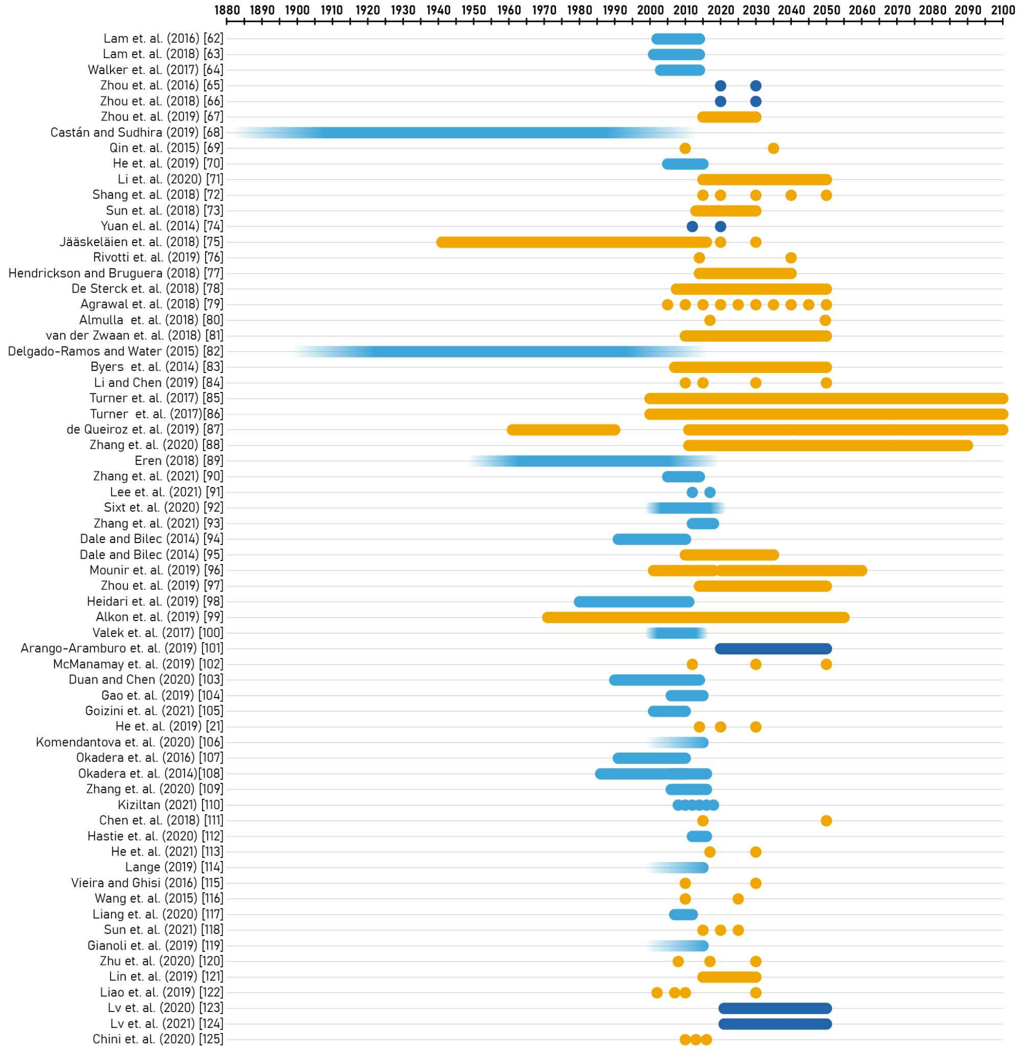

Figure 6. Distribution of analyzed periods. Past periods are presented in light blue, past and future periods in orange, and future periods in dark blue [21,62–125].

Figure 4 shows that 89% of the articles analyzed periods and that they had a more even representation of the past and future than articles on single events. To add to this analysis, Figure 6 shows the temporal position of all articles on periods. While they can be seen to have a more diverse profile of the past than articles on single events, they share the same lack of extended analysis of the historical background. Instead of advancing the historical understanding, articles on past periods are instead mainly focused on numerical modeling and often without consideration of other aspects. Only seven out of 57 articles that analyzed past periods embraced other factors, such as Eren [89] and Castan-Broto and Sudhira [68], which focused on the origin of the water and energy sectors in Turkey and India, respectively.

Figure 6 also illustrates the spread of the analyzed periods towards the future, showing, for instance, concern about long-term assessment even at the century-level. It is also possible to see that most articles in this category concentrate on the medium- and long-term, ranging from the mid-20th century until the end of the 21st century. A common topic for these studies was impact assessments of the climate crisis, either through its effects on natural resources, implementation of policies, infrastructural changes, or technological shifts.

3.2. Temporal Motivation

Figure 4 shows that 51% of the articles had arbitrary motivations, i.e., that no specific reasons for the choice of studied time were presented. Instead, the motivation behind these studies was often given as a need to find improvements to current water and energy management or to evaluate new methodologies. Thus, the choice of time is primarily based on the availability of the most updated or extensive information [22,38,55,57–59]. For articles on single events, 62% had arbitrary motivations, which all focused on past events. Besides evaluating new methodologies, a common motivation in this type of studies was to analyze the most updated status of the WEN in an area. An issue with this latter motivation is that the most recently available data at the time of the analysis often risks being outdated, both at the time of analysis and time of publication (see Figure 5). Meng et al. [59] gave an illustrative example of this issue by showing that there was a decrease in water consumption by 33% in the coal mining process and by 40% in coal preparation process in the US between 2014 and 2017. This shows that even a few years can generate significant uncertainties in the assessments of water usage, which is a general issue for studies where the motivation is to analyze the most updated status of the WEN, which is a common feature in studies of single past events.

In addition, 49% of the articles had a determined temporal motivation (Figure 4). In articles with a determined motivation, the underlying motivators are important elements, as they act as links between the discussion provided by the article and water–energy issues. These motivators can be induced due to management aspects (e.g., policies and plans) or environmental conditions (e.g., extreme weather events). Table 1 summarizes the main motivators used in articles with determined temporal motivations.

Table 1. Main motivators underlying the determined temporal motivations.

Temporal Position of Motivator	Motivator
Past (temporal trigger)	Extreme events, such as intense droughts Critical events such as water and energy crises Changes to policies on a national or international level Infrastructure changes
Future (temporal target)	Future policy implementation, e.g., on a local, national, or international level Climate change impacts Future infrastructure changes due to plan or policy adaptation

The role of temporal triggers can be clearly seen in examples such as Zhang et al. [56] and Zhang et al. [44], who used infrastructure changes that promoted an expansion of the electricity transmission lines around China, in turn implying a virtual water transfer, as a temporal trigger to contextualize the need for the temporal analysis. Lam et al. [63] and Lam et al. [62] used the Millennium Drought in Australia in the early 2000s as a temporal trigger to analyze how decision-making after the drought shaped the current water and energy consumption.

While temporal triggers based on extreme weather events or the introduction of policies are common, there is a lack of temporal triggers grounded in disruptive social events. One exception comes from a study of Barcelona, which saw an increase in poverty after the economic crisis in 2008, causing water and energy to become unaffordable to large parts of the low-income population. After 2015, the high water–energy insecurity raised the debate about integrated solutions, which was used as a temporal trigger for the analysis of Yoon et al. [126]. Similarly, Williams [127] used the heated debate about seawater desalination in California (US) as a temporal trigger for discussing water–energy policies based on literature and stakeholder opinions.

Figure 4 also shows that, for 82% of studies of future events, the temporal motivation is determined, i.e., using temporal targets. Table 2 summarizes the temporal targets used, including their sources and plans. This summary indicates that it is political objectives which serve as the principal motivator for future-oriented WEN research.

Table 2. Summary of type of temporal targets and their sources.

Type of Target	Source	Ref.
National social and economic planning	Chinese five-years plan and 3 Red Lines	[65–67,69–74]
National energy and climate planning	Finland's National Energy and Climate Strategy	[75]
Infrastructure plans	Country Partnership Strategy: Kazakhstan 2012-2016	[76]
Regional policy and associated change to infrastructure	California's Sustainable Groundwater Management	[77]
Urban planning	Delivering London's energy future: the mayor's climate change mitigation and energy strategy	[78]
Planned projects	Climate Leadership Plan—Alberta, Canada	[79]
International climate agreements	Paris Agreement	[80,81,83–88,121]

3.3. Type of Research and Temporal Detail of Data

The summary of the type of research and its association to the other temporal categories is presented in Figure 7.

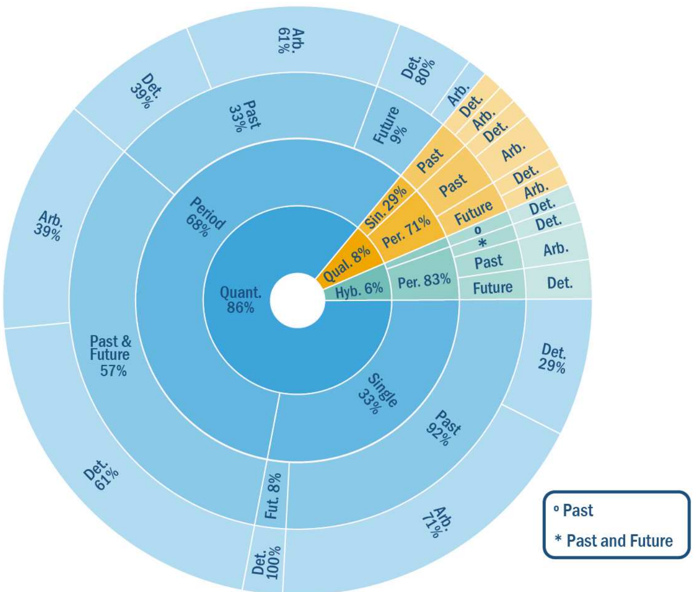

Figure 7. Summary of type of research, temporal extension, temporal position, and temporal motivation of the 96 articles.

It shows that 86% of the articles used quantitative approaches, mainly through accounting of water and energy, life cycle assessment, econometric models, and multivariate statistics. Previous studies, such as Dalla Fontana et al. [30] and Wiegleb and Bruns [36], have pointed out that most of the WEN studies are based on quantitative approaches, which these results confirm. The literature reviewed also showed that most WEN studies are grounded in economic and technocratic assessments, which can explain the predominance of quantitative approaches.

Within the quantitative approaches, a common methodology is the input–output analysis (IOA). This methodology is especially popular in quantitative studies of past events with arbitrary motivation (31% of all articles, Figure 7). An issue with IOA regarding the temporal understanding is the requirement for detailed input–output tables, as these often are released with long time intervals. The data requirement this results in thus plays a decisive role in the temporal extension of the analysis, which explains why the data used in many single events with arbitrary temporal motivation is outdated. This is sometimes clearly acknowledged in the articles, for instance Liao et al. (2020) [42], which stated that the input–output table from 2010 was the only available option, as well as other [39,41,45,46,48–51,54]. Such cases are even more pronounced when using global databases for IOA [40,41,43,45,46,52], where the update rate of the data often is slower than for national cases. In some cases, workarounds were applied to solve the lack of data, such as done by Zhang et al. [93] by updating and adjusting the outdated IO table using an algorithm known as RAS [128,129].

In addition to data availability, data quality is another essential feature influencing IOA, as highlighted by Okadera et al. [37]. This study presented three regional input-output tables (1997, 2002, and 2007) available for Liaoning Province, China. While it may be assumed that the latest one would have the most accurate data, high discrepancies were found in the 2007 table, prompting the authors to use the data from 2002 instead of 2007 to reduce uncertainties.

Data availability is also a limitation for other types of studies than single events using IOA. One example is Zhang et al. [90], who showed that their analysis of the Chinese electricity transmission lines only went up to 2014 because this was the last available public information. Similarly, Lee and Kim [91] based their analysis on data from nine years prior to publication. This data limitation can also impact the continuity of the analysis, as shown in Figure 6. In summary, these examples show that the choice of methodology and resulting data requirements directly influence the temporal extension of studies.

While there is a clear preference for quantitative approaches in WEN studies (86%), some studies use qualitative (8%) and hybrid methods (6%) (Figure 7). Several of the qualitative studies addressed the historical development of the relationship between water and energy, such as in Castán Broto & Sudhira [68] and Eren [89]. Castán Broto and Sudhira [68] developed the timeline of the urban background of the WEN in Bangalore, India, since 1883, by taking an urban landscape perspective to associate broader political changes to infrastructure practices. The objective was to analyze the temporal evolution of the spatial patterns that resulted from social and institutional practices. Eren [89] explored the development of hydroelectricity infrastructure in Turkey based on in-depth and semi-structured interviews, focus groups, surveys, documentary research, policy analysis, and stakeholder observations. They showed how the energy market transformation and privatization have generated growing socio-economic-environment impacts in the region around the Ikizdere River Basin since 2008.

Examples from the review showed that qualitative methodologies enabled an exploration of policy changes and inclusion of additional information sources, such as stakeholders' opinions. For instance, Sixt et al. [92] analyzed the political changes and institutional policy coordination in the water and energy sectors in China and the US. The goal was to assess to what extent different water and energy policies could enable or hinder joint governance between the two industries. In addition, Williams [127], Valek et al. [100], and Moss and Huesker [130] used stakeholders' interviews to understand the water–energy situation in a socio-economic context. The use of stakeholders' information adds a subjective perspective to the analysis, thereby giving insights into aspects of the WEN that often are neglected. These examples also show that using qualitative approaches for temporal analyses can enable an understanding of the current conditions as a process over time.

Qualitative approaches can also guide the analysis of the WEN future, which was the case for 29% of the qualitative articles, and 18% of all articles on future events (Figure 7). Komendantova et al. [106] created backcasting scenarios to 2040, which, according to forecasts, was expected to mark the aggravation of water scarcity in the Arab Region. The goal was to assess stakeholders' perceptions in different sectors about potential coupled water and energy management. Gianoli and Bhatnagar [119] used stakeholders' information to provide insights based on forecast scenarios from the national climate change plan about technological options to be applied in Cuencas, Ecuador. Lange [114] used a comprehensive literature review to investigate possible future technologies in the MENA region's water–energy system based on climate change impacts.

The use of hybrid methodologies has been advocated by several researchers [29,30,36], but only a few of the reviewed articles applied them (6%, Figure 7). Moreover, the use of quantitative and qualitative methodologies in these articles was generally not equal. For instance, Delgado-Ramos [82] quantified greenhouse gas emissions linked to Mexico City's metabolic water but mainly used qualitative methods to investigate the development of the WEN by presenting main temporal milestones in policies and relationships between stakeholders. Komendantova et al. [106] mainly used qualitative information on stakeholders' preference to model future scenarios in Jordan to 2040 based on backcasting approach. In contrast, Almulla et al. [80] mainly focused on quantitative techniques to improve modeling of the Drina River Basin, Germany, and understand the role of WEN to boost transboundary cooperation, while also including workshops, meetings, and conversations between stakeholders and researchers. The remaining two hybrid articles [78,105] used a System Dynamics methodology with both qualitative and quantitative data to create iterative models to represent issues and policy alternatives.

4. Recommendations

The literature review identified several key features of the temporal understanding in current WEN research. Based on these findings, a set of main gaps to improve the temporal understanding was identified, which are presented in Table 3.

Table 3. Summary of main gaps in the temporal understanding of WEN research.

Gap	Critical Issues
I—Methodological diversity	Excessive use of quantitative methodologies limits a comprehensive temporal understanding.
II—Temporal motivation	Half of the reviewed articles do not present any temporal motivation, thereby lacking lacks links to specific water–energy issues. This is especially important for studies of single past events.
III—Qualitative data usage	The low use of qualitative data decreases the temporal contextualization.
IV—Analysis focusing on social and political aspects	Social and political factors are directly related to a specific time; however, they are underrepresented in WEN studies.
V—Updated date	The need to present the current WEN situation requires updated data, which is not satisfactory for most studies with this focus.
VI—Analysis of historical background	Studies focusing on past events often do not explore the historical background of the processes linked to WEN.

We suggest that the identified gaps can be addressed through three main points: increasing methodological diversity (I, III and IV), enhancing historical development (I–VI), and improving and diversifying data use (III and V).

4.1. Increasing Methodological Diversity

As shown by this literature review, there is an overwhelming focus on quantitative approaches, making methodologies such as IOA hegemonic. This quantitative focus leads to certain limitations in understanding the future of the WEN as it tends to neglect important temporal interactions in demographic and economic structures, political interventions, and actors' behaviors. Without necessary complements to the quantitative approach to address these types of interactions, the robustness of the conclusions is likely to diminish.

Therefore, one of the key challenges to improve the temporal understanding of the WEN is how to introduce new types and combinations of methodologies. By building on the advantages of different methodologies, new perspectives on temporal features of current water–energy issues can be identified. Based on the literature review, Table 4 presents the strengths and weaknesses of quantitative and qualitative methodologies regarding the temporal understanding in WEN research.

Table 4. Main strengths and weaknesses of qualitative and quantitative approaches for the temporal understanding of the WEN.

Type of Research	Strength	Weakness
Quantitative	Allows to track the changes of the interlinkages between water and energy	Limits the analysis to measurable physical or economic units
	Explores the WEN relationship based on technological and economic changes	Loss of social and political dynamics and the role of stakeholders in the process
	Analysis of extensive dataset and potential to identify statistical patterns	Exclusion of non-quantified components of the WEN
Qualitative	Inserts social dynamics and political developments in the temporal contextualization	Limited by sample size, with difficulties to generalize the findings to other areas and times
	Includes stakeholders' opinions and provides a better understanding of the motivations and perceptions of actors	Inserts bias and subjectivity in the temporal analysis, and a time-consuming data collection process

Given the quantitative predominance, one way to increase methodological diversification is to insert methodologies from social sciences, which in addition to complementary perspectives also would allow for the inclusion of more qualitative data. By strengthening the influence of qualitative data, the development of the WEN could be tracked with added detail, primarily as it improves the temporal motivation by inserting previously neglected yet important aspects, such as demographic and economic structures, political interventions, and actors' behaviors. An example of this is Delgado-Ramos [82], who presented combined temporal milestones, such as policy changes, with a quantitative analysis of the WEN in Mexico City. Other examples are Lam et al. [63] and Lam et al. [62], who reinforced the need for studies using the Millennium Drought in Australia as temporal motivation. These studies show that both quantitative or hybrid methodologies can enhance the temporal understanding of the WEN by applying a better temporal contextualization. This can help to identify neglected connections, such as power imbalance between sectors, and long-term impacts across multiple segments of society.

Diversification of the methodologies can also advance the understanding of the future. Future studies in WEN research are often grounded in quantitative analyses focused on interactions between technologies, resources, material flows, and material costs. However, WEN issues are super wicked problems [131] that will "at some point be too acute, have had too much impact, or be too late to stop or reverse" [132]. Therefore, studies must take a long-term perspective and use methods that promote learning and negotiation. The insertion of participatory methods to involve stakeholders' perspectives can enrich the research process and evaluate whether determined changes may be acceptable or not. Therefore, involvement of stakeholders has been acknowledged as crucial for nexus implementation [133,134]. Inspiring examples of this from the literature review were Komendantova et al. [106] and Gianoli and Bhatnagar [119], who both used stakeholders' information to construct future scenarios before creating models, and Yoon et al. [126] who used stakeholders to assess public opinion about the water–energy insecurity in Barcelona.

4.2. Enhancing the Understanding of the Historical Development of the WEN

Based on the review findings, we identified a tendency to see water–energy issues as emergent or recent problems. This trend reflects a common idea in the field that 'Every situation is an event unto itself' [135]. We suggest that this neglect of historical processes can be countered by strengthening the investigation of the temporal evolution of the relationship between the resources. An essential part of the temporal evolution is how the sectors were formed, such as those addressed in Turkey [89] and India [68]. In such cases, negative interaction between the water and energy sector is as old as the origin of the sectors. The analysis of an ancient root of the nexus in these cases was based on both primary (e.g., original data, reports, maps, painting) and secondary sources (e.g., articles). Other examples of historical WEN features that should be included in the analysis are investigations about environmental damages to water bodies due to energy generation, jeopardization of one sector to prioritize the other, impacts related to mismanagement on both sectors, and even the construction of social inequalities attached to WEN.

Another aspect relating to historical development is the lack of understanding of the role of policies and regulations, which in effect are tools to shape how the resources in the WEN are managed over time. Overall, many articles use policies and regulations to justify analyses of WEN, such as Yoon et al. [126] who discuss measures to mitigate the water–energy insecurity in Barcelona, Spain. However, few articles scrutinize the changes in these policies over time or show the long-term impact they had on resources management. An exception was Castán-Broto and Sudhira [68], who explored the evolution of policies linked to WEN in the case of Bangalore since 1883. They argued that many of the current impacts in the Bangalore WEN were linked to the privatization of the electricity sector, which was supported by changes in governmental regulation. This example shows how an analysis of the influence of policies can enhance the understanding of the WEN and the maintenance of trade-offs.

Similar to the role of policies and regulations, the understanding of the historical development can also be addressed by investigating technological evolution in a WEN context. The historical perspective of technology is vast in the energy field [136–140]. However, the literature review showed that there is a gap in how water resources have been used in energy systems from a nexus perspective.

4.3. Improving and Diversifying Data Use

Availability and use of data are critical constraints for the temporal understanding of the WEN. First, many articles pointed to the lack of updated datasets and problems in data quality regarding quantitative data. Regarding nexus, data availability is complicated as it is necessary to conciliate information about more than one sector. Considering the temporal aspect, one first step would be for authors to be aware of the rapid pace with which key WEN features can change, and thus the importance of using updated datasets. Another way to address this is by using analytical methods to recognize the temporal issues with the data, such as using the RAS algorithm on outdated IO tables, as shown in Zhang et al. [90].

Moreover, through ongoing technological and institutional development, increasing digitalization, and growing capacity of computational methods, the availability of data is likely to expand faster than the uptake of that data in research. Incorporating this expanding data availability in research is now an opportunity to generate new knowledge in WEN studies, but this requires a combination of hybrid methodologies and interest from researchers to actively look for and compile diverse types of data. A final point to improve data use is to push for an integrative monitoring and data generation effort between the scientific community and governments, in both the water and energy sectors, to provide updated, open, and free data.

Second, as previously mentioned, there is a significant gap in using qualitative data. One way to address this is by incorporating more qualitative methods, thereby making greater use of already available qualitative data while developing new strategies to include new qualitative data sources. Another recommendation is to generate new datasets by following the advice provided by Sovacool et al. [141], who argue that national institutions and statistical agencies should work to gather, compile, and provide social data on several geographical levels. Notably, we recommend that qualitative data should also be obtained from interviews with stakeholders, newspapers, reports, and qualitative data produced in social media. For instance, these qualitative data can provide information about technological acceptance, willingness towards policies, and social and economic barriers of stakeholders.

5. Conclusions

Guaranteeing water and energy is one of the biggest global challenges and led to the intensification of the debate about the WEN. Much focus has been dedicated on how to optimize the system, seek technological solutions, and quantify the links between the water and energy sectors. Despite this attention, we think that much still needs to be done, and specifically related to the temporal understanding of the water–energy relationship. Therefore, this review aimed to identify, categorize, and analyze the main temporal features in the current WEN literature.

From the literature review, a couple of key results were identified. First, it confirmed that the recent WEN literature has mainly used quantitative approaches (86% of the 96 reviewed articles). The second key result was the prevalence of period studies (69%) over single events (31%), showing a desire to track changes in the use of water by the energy sector over time. The third key result showed that 51% of the reviewed articles did not present a clear motivation for their choice of time. The fourth key result was the lack of historical understanding, which implies a weak understanding of the processes involved in the WEN. Finally, the last key point was how dependent the choice of time is on data availability and choice of methodologies.

Many new paths for future research about WEN can be extracted from this literature review. For instance, a set of recommendations were identified to improve the temporal understanding in WEN research. The understanding of the historical background of the WEN in specific areas needs to be enhanced, for instance by tracking the joint evolution of the water and energy sectors, policy changes, and technological shifts. We also encourage a better contextualization and link to temporal milestones. These improvements could in turn help the scientific community to communicate the findings to a broader audience and increase its influence on the WEN. Finally, a joint aspect regards diversification of both methodologies and data use, especially by inserting qualitative and hybrid methodologies. More qualitative data should also be included in WEN research, while also creating an effort within and outside academia to assure relevant, continuous, and reliable data.

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Appendix A. Methods—Literature Review

The initial sample was constructed first scrutinizing Scopus using the terms: "water–energy nexus", "water–energy", "water energy", "water energy nexus", "energy–water nexus", "energy water nexus", "energy water", "water for energy" and "energy for water" as search strings on title, abstract and keywords. The filters applied are:

- **Document type**. **Include** articles. **Exclude** conference paper, review, book chapter, book, editorial, note, conference review, short survey, erratum, data paper, business article, letter, retracted, report and undefined.
- **Document source. Include** journal. **Exclude** trade journal, book series, book, conference proceeding, undefined.
- **Subject area. Include** Environmental Science, Engineering, Energy, Earth and Planetary Sciences, Agricultural and Biological Sciences, Social Sciences, Business, Management and Accounting, Economics, Econometrics and Finance, Multidisciplinary, Decision Sciences, and Arts and Humanities. **Exclude** Chemistry, Chemical Engineering, Materials Science, Biochemistry, Genetics and Molecular Biology, Medicine, Physics and Astronomy, Computer Science, Mathematics, Nursing, Psychology, Immunology and Microbiology, Pharmacology, Toxicology and Pharmaceutics, Health Professions, Veterinary, Neuroscience, and Undefined.
- **Language. Include** English. **Exclude** Chinese, French, German, Spanish, Portuguese, Russian, Japanese, Polish, Italian, Arabic, Czech, Persian, Slovenian, Turkish, Bulgarian, Dutch, Hungarian, Korean, Slovak, Undefined.
- **Period. Include** articles from 2011 until 2021. **Exclude** articles older than 2010.
- **Keywords. Include** Water-energy Nexus, Water Energy, Energy-Water nexus, Water and Energies and Nexus. **Exclude** Water Supply, Sustainable Development, Climate Change, Article, Sustainability, Water Management, Water, United States, Water Resources, Energy Efficiency, Environmental Impact, Energy, Energy Utilization, Water Resource, Carbon Dioxide, Decision Making, Water Conservation, Water Use, Energy Use, Priority Journal, Energy Resource, Carbon, Life Cycle, Optimization, Agriculture, Evapotranspiration, Economics, Hydropower, Greenhouse Gases, Economic In addition, Social Effects, Water–energy–food Nexus, Groundwater, Desalination, Energy Conservation, Irrigation, Water Availability, Soil Moisture, Wastewater Treatment, Hydroelectric Power, Numerical Model, Electricity Generation, Energy Policy, Energy Balance, Land Use, Remote Sensing, Water Treatment, Resource Management, Carbon

Footprint, Food Security, Uncertainty Analysis, Urban Area, Electricity, Food Supply, Water Quality, Environmental Management, Food, Human, Investments, Ecosystems, Vegetation, Integrated Approach, Power Generation, Water Budget, Water Footprint, Climate Models, Controlled Study, Life Cycle Analysis, Energy Consumption, Land Surface, Environmental Protection, Greenhouse Gas, Runoff, Sensitivity Analysis, Ecology, Gas Emissions, Renewable Energy, Costs, Water Pollution, Alternative Energy, Life Cycle Assessment, Solar Energy, Species Richness, Water Demand, Rivers, Watersheds, Life Cycle Assessment (LCA), Carbon Emission, Trade-off, Waste Management, Economic Analysis, Forestry, Environmental Impact Assessment, Drought, Emission Control, India, Biomass, Crops, Eurasia, Europe, Environmental Policy, Hydrological Modeling, Reservoirs (water), Australia, Biodiversity, Input–output Analysis, Population Statistics, Agricultural Robots, Planning, Performance Assessment, Recycling, Risk Assessment, Energy Planning, Environmental Sustainability, Hydroelectric Power Plants, Renewable Energies, Renewable Resource, Water Planning, Electric Power Generation, Urban Planning, Eddy Covariance, Global Warming, Modeling, Assessment Method, Evaporation, Nonhuman, Wastewater, Water Use Efficiency, Commerce, Cost Benefit Analysis, Spain, Stakeholder, Climate, Climate Effect, Comparative Study, Hydrology, Water Consumption, Energy Resources, Precipitation (climatology), Quantitative Analysis, Supply Chains, Animals, Canada, Energy Management, Surface Measurement, Temperature, Computer Simulation, Seasonal Variation, Data Set, Brazil, Demand Analysis, Rain, Regression Analysis, Budget Control, Catchments.

The final search string was carried out on 20 October 2021, and is composed by:

TITLE-ABS-KEY ("water–energy nexus" OR "water–energy" OR "water energy" OR "water energy nexus" OR "energy–water nexus" OR "energy water nexus" OR "energy water" OR "water for energy" OR "energy for water") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (EXCLUDE (SUBJAREA, "CHEM") OR EXCLUDE (SUBJAREA, "MATE") OR EXCLUDE (SUBJAREA, "CENG") OR EXCLUDE (SUBJAREA, "BIOC") OR EXCLUDE (SUBJAREA, "PHYS") OR EXCLUDE (SUBJAREA, "MEDI") OR EXCLUDE (SUBJAREA, "COMP") OR EXCLUDE (SUBJAREA, "MATH") OR EXCLUDE (SUBJAREA, "NURS") OR EXCLUDE (SUBJAREA, "PHAR") OR EXCLUDE (SUBJAREA, "IMMU") OR EXCLUDE (SUBJAREA, "PSYC") OR EXCLUDE (SUBJAREA, "HEAL") OR EXCLUDE (SUBJAREA, "NEUR") OR EXCLUDE (SUBJAREA, "VETE") OR EXCLUDE (SUBJAREA, "Undefined")) AND (LIMIT-TO (EXACTKEYWORD, "Water–energy Nexus") OR LIMIT-TO (EXACTKEYWORD, "Water Energy") OR LIMIT-TO (EXACTKEYWORD, "Energy–water Nexus") OR LIMIT-TO (EXACTKEYWORD, "Water and Energies") OR LIMIT-TO (EXACTKEYWORD, "Nexus"))

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