

Review

Greywater as a Future Sustainable Energy and Water Source: Bibliometric Mapping of Current Knowledge and Strategies

Sabina Kordana-Obuch ^{1,*} , Mariusz Starzec ¹ , Michał Wojtoń ^{1,2} and Daniel Słyś ¹ ¹ Department of Infrastructure and Water Management, Rzeszow University of Technology, al. Powstańców Warszawy 6, 35-959 Rzeszow, Poland² Doctoral School of Engineering and Technical Sciences, Rzeszow University of Technology, al. Powstańców Warszawy 12, 35-959 Rzeszow, Poland

* Correspondence: sk@prz.edu.pl

Abstract: The use of greywater reduces the consumption of many resources and is an effective tool for achieving Sustainable Development Goals. In order to assess the rationality of its use as an alternative source of energy and water in buildings, a holistic literature review was carried out based on a bibliometric analysis of publications in these fields. The main bibliographic source was the Web of Science database. This review contributed to a better understanding of the analyzed research field. It also revealed trends in greywater energy recovery and recycling research, indicating that these are developing fields. In recent years, there has been a marked increase in the number of publications on the most popular ways of using greywater in buildings, with the territorial scope of research carried out in the greywater recycling domain being considerably larger than research on greywater energy recovery. The analysis revealed poor cooperation between different universities, especially in the field of greywater energy recovery. In light of previous literature reviews, some important research gaps and further proposals for future research were also identified. They concern, in particular, the simultaneous use of greywater as an alternative source of energy and water. Together with the findings of other researchers and people related to the subject matter, this review can contribute to the further development of greywater energy recovery systems and greywater recycling systems.

Keywords: bibliometric analysis; Bibliometrix; VOSviewer; drain water heat recovery; greywater energy recovery; greywater recycling; building



Citation: Kordana-Obuch, S.; Starzec, M.; Wojtoń, M.; Słyś, D. Greywater as a Future Sustainable Energy and Water Source: Bibliometric Mapping of Current Knowledge and Strategies. *Energies* **2023**, *16*, 934. <https://doi.org/10.3390/en16020934>

Academic Editor:
Constantinos Noutsopoulos

Received: 19 December 2022
Revised: 9 January 2023
Accepted: 11 January 2023
Published: 13 January 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The future of tomorrow is sustainable development (SD), according to which meeting the needs of the present generation should be done without compromising the ability of future generations to meet their own needs [1]. In order to fulfill the SD goals, 17 Sustainable Development Goals (SDGs) were developed [2]. These goals cover various aspects of life, including ensuring access to reliable and affordable clean energy sources [3] and water [4]. However, the possibilities of implementing SDGs are conditioned not only by the degree of technological advancement but also by national SDG policies [5]. Implementation of relevant strategies, programs, and plans is also very important [6]. On the other hand, Dumitrescu et al. [7] point out the need to use pedagogical tools to achieve meaningful social transformation from an SD perspective. Considering that the success of the SDGs will not be possible without the commitment of individuals, it is necessary to further promote sustainable solutions and make the communities aware of their use in the immediate environment, mainly in buildings. Indeed, the application of small systems has many advantages, among which the reduction of distribution and transport costs and the reduction of energy consumption deserve special attention [8].

The use of greywater (GW) can contribute to the implementation and success of SDG 6, “Clean water and sanitation,” and SDG 7, “Affordable and clean energy” [2]. This type of

domestic wastewater is generated every day in sanitary facilities such as shower baths, bathtubs, sinks, and washing machines and it can be a source of water used for purposes that do not require the quality of drinking water [9]. Widespread recycling of GW would contribute to the protection of water resources [10] and increase their availability [11]. Reducing potable water consumption in the city would also result in reduced energy consumption for the transport and treatment of water and wastewater [12,13]. Cureau and Ghisi [14] further indicate that in addition to the environmental benefits of reduced water consumption, reduced wastewater production, and reduced electricity consumption, the positive effects of implementing greywater recycling systems (GWRs) at the city scale would also be felt by the local utility. In addition, wastewater acts as a renewable energy carrier [15,16]. In the case of greywater, this energy can be recovered and successfully used, for example, to preheat tap water [17], while contributing to the reduction of greenhouse gas emissions [18]. Considering that heat recovery is a key issue with regard to the growth of energy management efforts [19,20], greywater can be treated as an effective alternative to traditional energy sources for preparing domestic hot water (DHW) [21]. When heat pumps are used, the recovered energy can also be used for other purposes [22].

Despite the undoubted advantages related to the recycling of greywater and the use of energy contained in it, some authors point out the need to incur relatively high investment outlays [23] and the lack of financial incentives [24]. Another problem may be the lack of experience in the operation of such systems and relevant guidelines [25], as well as the lack of social acceptance for the use of greywater for various purposes [10], which is a consequence of insufficient information about the environment and its protection. A considerable influence on the approach to the use of greywater in existing buildings also has, in some cases, the need for significant interference in the way internal installations are carried out [21]. In the case of devices dedicated to heat recovery from greywater, additional attention should be paid to the low efficiency of some solutions [26]. On the other hand, a barrier to GWRs implementation may be the concern about the quality of GW [27]. The existence of both opportunities and limitations related to the recovery of energy and water from GW creates opportunities for further research on the rationality of using greywater generated in buildings. One of the most common methods of collecting the latest research results in a given field is a literature review. Over the past few years, a number of review articles have been published on greywater heat recovery and recycling. These articles have appeared in various journals representing major publishers. The most significant of these are shown in Tables 1 and 2. However, none of the indicated review articles addresses the issue of the combined use of GWRs and greywater heat recovery systems. There are also no papers whose main purpose would be to perform a bibliometric analysis of the subject matter, while this approach allows one to understand the structure of knowledge in the field, providing a start in the implementation of publications by young researchers [28]. On the other hand, when analyzing review publications in the field of greywater recycling, one can see a tendency to focus on its quality and treatment options. In recent papers, technical, hydraulic, political, or social issues are often directed to the background. It should also be noted that most of the review articles on this topic were published several years ago. Therefore, it does not consider the latest research results and the most recent developments. More recent and up-to-date are review papers in the field of greywater heat recovery, which prove the importance and relevance of this topic. However, their number is much lower, and greywater energy recovery is not always a major research issue. Noteworthy is also the relatively high number of citations of review papers covering the problem of using greywater. For example, only in 2021, the review papers from Table 1 were cited on average almost nine times. The papers included in Table 2 more than fourteen times.

Table 1. Review papers in greywater energy recovery domain.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Nagpal et al. [29]	2021	Review of publications on wastewater heat recovery at various scales, from buildings to wastewater treatment plants	<i>Water</i> (MDPI)	22
El Hage et al. [30]	2020	Overview of domestic heat recovery systems, including drain water heat recovery systems	<i>Energy Sources, Part A: Recovery, Utilization, And Environmental Effects</i> (Taylor & Francis)	19
Pomianowski et al. [31]	2020	Collecting and presenting the latest publications on improving the energy efficiency of domestic hot water preparation systems	<i>Renewable and Sustainable Energy Reviews</i> (Elsevier)	38
Piotrowska et al. [32]	2020	Review of research papers in the field of heat recovery in residential sewage installations	<i>Resources</i> (MDPI)	6
Mazhar et al. [33]	2018	Review of papers on non-industrial heat harnessing from wastewater	<i>Energies</i> (MDPI)	21

* Number of citations according to the Web of Science database (as of 30 September 2022).

Table 2. Review papers in greywater recycling domain.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Filali et al. [34]	2022	Overview of techniques used to treat and recover greywater, with particular emphasis on the risk of occurrence and spread of “SARS-CoV-2”	<i>Sustainability</i> (MDPI)	0
Elhegazy and Eid [35]	2020	Review of the state of knowledge in the field of characteristics of greywater	<i>Water Science & Technology</i> (IWA Publishing)	7
Roshan and Kumar [36]	2020	An overview of end-use water consumption in 16 countries with a proposal for specific greywater recycling models	<i>Journal of Environmental Management</i> (Elsevier)	29
Vuppaladadiyam et al. [37]	2019	Overview of various aspects of greywater use (production sources, features, barriers, and global reuse scenarios)	<i>Reviews in Environmental Science and Bio/Technology</i> (Springer)	37
Oteng-Peprah et al. [38]	2018	Literature review on the quality of greywater, its components, methods of purification and social attitude	<i>Water, Air, & Soil Pollution</i> (Springer)	90
De Gisi et al. [39]	2016	A review of the state of the art on the use of graywater in buildings in the context of its qualitative and quantitative characteristics, guidelines, treatment systems, and case studies	<i>Civil Engineering and Environmental Systems</i> (Taylor & Francis)	51

Table 2. Cont.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Pinto and Maheshwari [40]	2015	An overview of aspects related to different greywater treatment methods and the impact of its use for irrigation on soil quality and plant growth	<i>Chinese Journal of Population Resources and Environment</i> (Taylor & Francis)	12
Li et al. [41]	2010	Characteristics of domestic rainwater harvesting and greywater treatment systems with an assessment of possible water savings in Irish homes	<i>Desalination</i> (Elsevier)	109
Maimon et al. [42]	2010	Assessing the adequacy of various regulations in the context of ensuring the safe use of greywater for onsite irrigation	<i>Environmental Science and Technology</i> (American Chemical Society)	93
Li et al. [43]	2009	Evaluation of greywater treatment and reuse schemes	<i>Science of the Total Environment</i> (Elsevier)	348
Exall [44]	2004	Characteristics of the status of greywater reuse in Canada	<i>Water Quality Research Journal of Canada</i> (Canadian Association on Water Quality)	22

* Number of citations according to the Web of Science database (as of 30 September 2022).

Considering the above, the purpose of this paper is to present a bibliometric analysis of the literature on the use of greywater in buildings as a source of energy and water. The article presents publications on systems design, simulation of their operation, and impact on external infrastructure and the environment, as well as the profitability of the application. The analysis is divided into three parts. In the first, only articles dealing with the topic of heat recovery from greywater were analyzed. The second part addresses issues related to greywater recycling. On the other hand, the last part presents the results of the bibliometric analysis carried out considering both applications of this medium. This paper can help researchers understand the current situation of the use of greywater for various purposes, identify the challenges associated with it, and identify directions for further research.

2. Materials and Methods

A holistic review of the literature on the feasibility of using greywater as a sustainable source of energy and water was carried out based on bibliometric analysis. This approach is now widely used in analyses of both energy transitions [45,46] and water resources [47,48]. It allows linking existing research to studies in the near future, forecasting future analyses on trends related to greywater use [49]. By relying on quantitative techniques, it helps mitigate the bias that can be present in systematic literature reviews. This allows the results to guide authors in the selection of topics with the greatest impact, as well as help find suitable collaborators.

2.1. Collection of Bibliographic Data

The results were based on an exhaustive bibliometric analysis of articles on the use of greywater that were published in the 21st century (2001–2022). Their identification was made possible by using the Web of Science database. It is one of the most recognized multi-disciplinary databases in the world. It classifies journals according to their productivity and number of citations, thus assessing their power of influence [50]. The publication search was performed by analyzing article titles, abstracts, and keywords (both Author Keywords and Keywords Plus). Search queries were formulated separately for publications

on greywater energy recovery and articles addressing greywater recycling in buildings (Table 3). The data were downloaded on 30 September 2022.

Table 3. Web of Science queries. The asterisk (*) was used to find both plural and singular forms of the words.

Domain	Query Syntax	No. of Results
greywater energy recovery	(AB = ("drain water" OR "drainwater" OR "shower water" OR "shower" OR "grey water" OR "greywater" OR "gray water" OR "graywater") OR TI = ("drain water" OR "drainwater" OR "shower water" OR "shower" OR "grey water" OR "greywater" OR "gray water" OR "graywater") OR AK = ("drain water" OR "drainwater" OR "shower water" OR "shower" OR "grey water" OR "greywater" OR "gray water" OR "graywater") OR KP = ("drain water" OR "drainwater" OR "shower water" OR "shower" OR "grey water" OR "greywater" OR "gray water" OR "graywater")) AND (AB = ("heat recovery" OR "energy recovery" OR "heat exchanger" OR "heat source" OR "source of heat") OR TI = ("heat recovery" OR "energy recovery" OR "heat exchanger" OR "heat source" OR "source of heat") OR AK = ("heat recovery" OR "energy recovery" OR "heat exchanger" OR "heat source" OR "source of heat") OR KP = ("heat recovery" OR "energy recovery" OR "heat exchanger" OR "heat source" OR "source of heat")) AND (TI = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic") OR AB = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic") OR AK = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic") OR KP = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic")) AND PY = (2001–2022)	110
greywater recycling	(AB = ("grey water" OR "greywater" OR "gray water" OR "graywater") OR TI = ("grey water" OR "greywater" OR "gray water" OR "graywater") OR AK = ("grey water" OR "greywater" OR "gray water" OR "graywater") OR KP = ("grey water" OR "greywater" OR "gray water" OR "graywater")) AND (AB = ("recycl*" OR "harvest*" OR "reus*" OR "reclaim*") OR TI = ("recycl*" OR "harvest*" OR "reus*" OR "reclaim*") OR AK = ("recycl*" OR "harvest*" OR "reus*" OR "reclaim*") OR KP = ("recycl*" OR "harvest*" OR "reus*" OR "reclaim*")) AND (AB = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic") OR TI = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic") OR AK = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic") OR KP = ("building*" OR "house*" OR "dwelling*" OR "flat*" OR "apartment*" OR "bathroom*" OR "kitchen*" OR "residential" OR "domestic")) AND PY = (2001–2022)	840

2.2. Data Preparation

The collected data were filtered, as shown in Figure 1. In order to include in the review only articles published by reputable, large-scale publishers, papers that are not indexed in the Scopus database were excluded. All non-English publications were also discarded. As a result, the size of the databases was reduced to 105 and 767 records, respectively, for publications in the fields of greywater energy recovery and greywater recycling. The final step in preparing the data for the bibliometric analysis was the human exclusion of records.

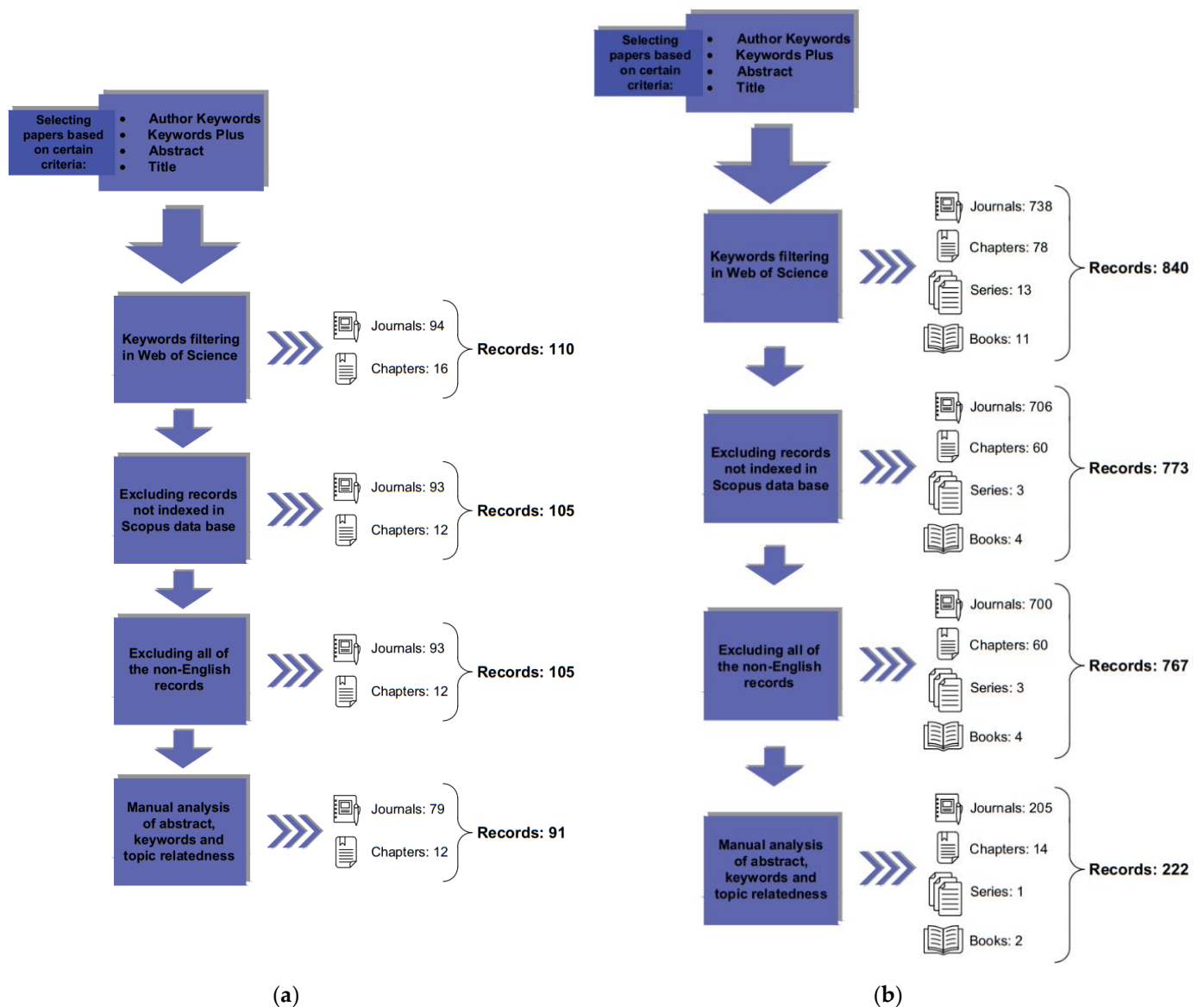


Figure 1. Indication of studies for bibliometric analysis: (a) greywater energy recovery domain; (b) greywater recycling domain.

In the case of publications in the field of energy recovery from greywater, the analysis included those that concerned the presentation of the design of drain water heat exchangers dedicated to use in bathrooms and kitchens, the simulation of their operation and cost-effectiveness of application in buildings, as well as the impact on the environment, infrastructure, and society. The review also included publications analyzing combined systems. Articles focusing on the issues of waste management and wastewater treatment, as well as energy recovery within sewage networks, have been excluded. In addition, publications where the main research topic was heat recovery from sewage sludge were not

analyzed. As a result of filtering the results, another 14 records were discarded. Therefore, the analysis included 91 publications on greywater energy recovery in buildings.

The review of research in the greywater recycling domain includes publications addressing tap water savings, financial savings from reduced water supply charges, as well as energy savings resulting from reduced water consumption. Articles assessing the reliability of GWRs, their environmental impact, and the framework of policies implemented in this area were also considered. Among the important aspects discussed in the publications, there was also society's attitude to the use of greywater in buildings. In addition, as in the case of greywater energy recovery systems, the bibliometric analysis included articles describing combined systems. This applies to both the combined use of various alternative water sources and the use of greywater with unconventional energy sources. Articles whose main purpose is to assess the quality of greywater and describe their treatment technologies were excluded. The analysis also did not include publications examining the effects of greywater irrigation on plants and soil quality and the possibilities of resource recovery from greywater. The analysis carried out by a human showed that the vast majority of papers on the recycling of greywater focus on the qualitative aspects of its use. As a result, 222 records were finally included in the analysis.

2.3. Bibliometric Analysis

The visualization of bibliometric networks is often referred to as “science mapping”. It is an effective tool for analyzing the network of connections between publications, journals, keywords, or researchers [51]. In order to make the visualization of the identified relations available to a wider audience, dedicated software was developed. Some of the most widely used software is VOSviewer [52] and Bibliometrix [53]. These tools are used in both energy review articles [54,55] and research papers [56]. In this review, VOSviewer v. 1.6.18 (Leiden, The Netherlands) and Bibliometrix (Biblioshiny 4.0 app; Naples, Italy) software were used.

VOSviewer is a software that can be used to create and visualize bibliometric networks. It was developed at Leiden University. The networks created by VOSviewer are based on bibliometric data downloaded from scientific databases (e.g., Web of Science, Scopus). Data can be prepared as plain text and transformed into complex bibliometric networks, including co-occurrence, co-citation, and co-authorship relations of user-defined elements [52]. VOSviewer uses a measure of similarity called association strength [57]. The association strength s_{ij} between two items i and j can be calculated using Equation (1) [52].

$$s_{ij} = \frac{c_{ij}}{w_i w_j}, \quad (1)$$

where: c_{ij} specifies the number of co-occurrences of items i and j , w_i and w_j specifies the total number of occurrences of items i and j , respectively, or the total number of co-occurrences of these items.

The Bibliometrix package for R is a software developed by Massimo Aria and Corrado Cuccurullo in 2017. The software is based on the R language. Additionally, RStudio software was used to enable access to the Biblioshiny browser-based application. Bibliometrix is a complex tool for multiple bibliometric analyses. The software allows the generation of various charts and tables supporting the bibliometric analysis process [53]. On the other hand, Rstudio is an integrated package of software facilities for data calculation and manipulation, as well as a graphical display of received results. The RStudio is a coherent system of extensions and packages that is made by its community to fully utilize its capabilities.

3. Results and Discussion

The rational use of greywater in buildings reduces the consumption of many resources, such as water, heat, and electricity. In order to achieve full utilization of greywater, it is necessary to identify its resources, determine their availability, identify how to manage them, and find new reuse and recycling processes. Therefore, this section conducts a retrospective analysis of selected publications on the issue of greywater energy recovery, as

well as articles addressing greywater recycling in buildings. A thorough understanding of the processes and technologies of the two main ways of reusing greywater will help identify weaknesses and possible ways of implementing them together.

3.1. Greywater Heat Recovery

The importance of domestic hot water preparation in the balance of energy consumption in buildings has been clearly increasing in recent years. Amanowicz [58] indicates that this applies not only to the annual demand for energy but also to the selection of the peak power of the heat source. However, due to the complexity and multiplicity of factors determining the demand for domestic hot water, unambiguous prediction of its consumption is difficult [59]. Therefore, it is necessary to search for ways of preparing domestic hot water that will ensure the comfortable and reliable operation of the installation for many years. In the face of the current energy crisis and the increase in energy prices, the diversification of energy production is also gaining importance [60]. Østergaard et al. [61], after analyzing the feasibility of low-temperature heating in buildings, identified heat recovery from wastewater as an effective way to reduce energy for domestic hot water preparation. On the other hand, Wehbi et al. [62] noted that by using a wastewater heat recovery system, up to 50% of energy could be recovered in some cases.

The first articles on the use of energy carried by greywater appeared in 2001 [63,64]. These were technical notes in which the authors drew attention to the possibility of recovering energy contained in wastewater discharged from different therapy systems installed in the spa, including showers. For the next few years, the topic was not developed. It was not until 2009 that further publications appeared in which the issue of greywater energy recovery was addressed (Figure 2). Therefore, it can be assumed that the increased interest in energy conservation and the use of waste heat was related to the global economic crisis. Initially, these were articles on the comparison of different ways of preparing domestic hot water, including systems based on energy recovery from greywater [65,66]. In the following years, research began to focus on drain water heat recovery (DWHR) systems [67,68]. This confirms that heat recovery from drain water is a relatively new technology [69]. The authors analyzed both vertical [70] and horizontal [26] heat exchangers. Some publications that appeared at the time also highlighted the issues of using greywater as a lower energy source for heat pumps [71,72]. In the following years, research on energy recovery from greywater was continued, and the number of publications steadily increased. More and more emphasis was placed on the development and analysis of new DWHR units. For example, research by Morales-Ruiz et al. [73] and Torras et al. [74] concerned storage-type units. On the other hand, the subject of analysis for Gabor et al. [75] was the heat pipe heat exchanger. Some authors centered their research on assessing the possibility of cooperation between the DWHR system and the heat pump [76]. Others focused on evaluating the efficiency of the hybrid system [77]. The papers published after 2016 also included numerical analyses [78], which was probably due to the development and increase in the popularity of computer tools. The topics of articles published in recent years do not differ significantly from those of older publications. Analyses concerning the modeling of DWHR systems [79] and combined systems [80], the use of greywater as a lower energy source for heat pumps [81], and the assessment of the efficiency of new heat exchanger designs [21,82] are still being carried out. However, more and more publications address social, financial, and environmental issues. In order to show the scope of research undertaken in recent years, Table 4 presents selected new research papers on greywater energy recovery.

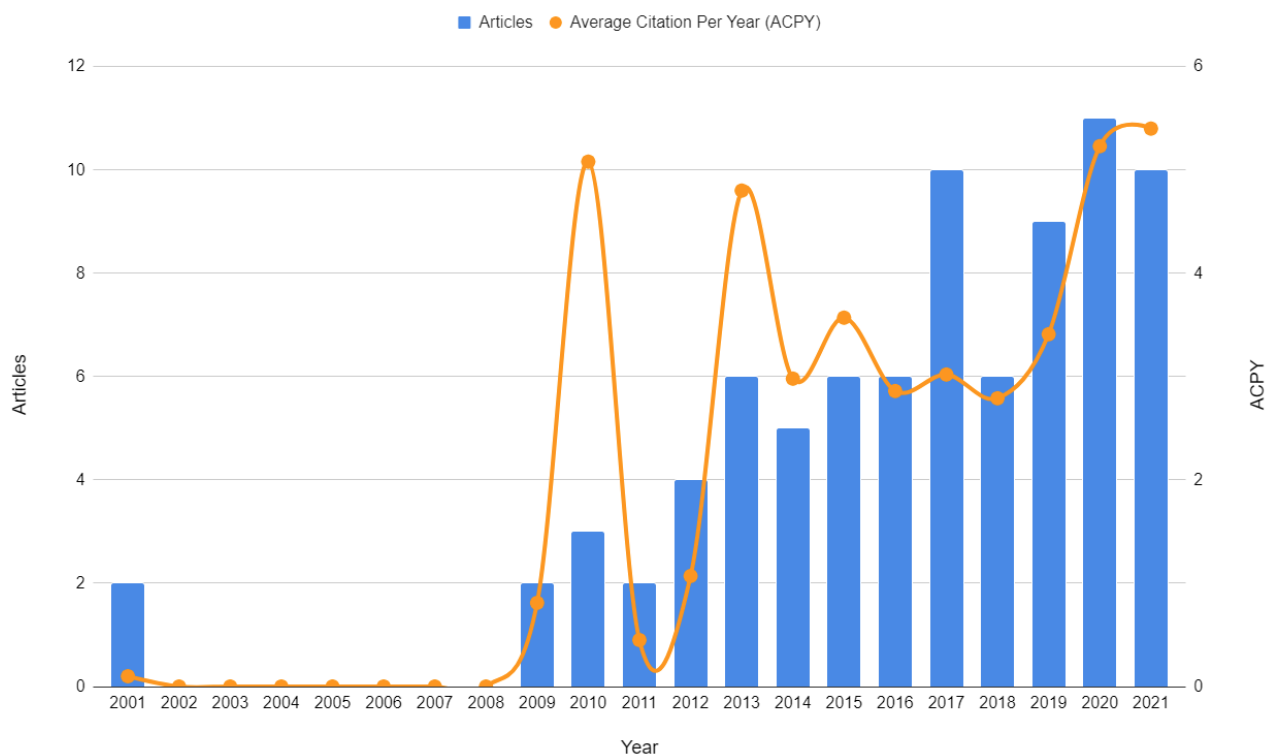


Figure 2. Publication trend in greywater energy recovery domain.

Table 4. Selected research papers from the last five years in greywater energy recovery domain.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Hadengue et al. [83]	2022	Evaluation of the potential of an active greywater heat recovery system to increase the efficiency of air source heat pumps. Greywater is used to preheat the air stream entering the heat pump's outdoor unit	<i>Applied Energy</i> (Elsevier)	5
Vavříčka et al. [84]	2022	Experimental evaluation of a new prototype of a horizontal plate heat exchanger for heat recovery from shower water	<i>Energy and Buildings</i> (Elsevier)	4
Manouchehri and Collins [85]	2022	Demonstration of various hydraulic configurations of an installation equipped with a falling-film drain water heat recovery unit using TRNSYS software	<i>Energies</i> (MDPI)	1
Sayegh et al. [86]	2021	Evaluation of the feasibility of a heat recovery system from drain water from sinks and washing machines in a typical hotel in Poland	<i>Science of the Total Environment</i> (Elsevier)	8
Kordana-Obuch et al. [87]	2021	Identification of factors affecting energy saving for water heating and assessment of society's willingness to use shower heat exchangers	<i>Energies</i> (MDPI)	5
Selimli and Abajja [88]	2021	Evaluation of potential energy savings resulting from the use of a heat exchanger attached to a dishwasher	<i>Water Environment Research</i> (Wiley)	2

Table 4. Cont.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Selimli and Eljetlawi [89]	2021	Experimental assessment of the potential of heat recovery from shower water using a horizontal and vertical connection of the helical coil and brazed plate heat exchangers	<i>Energy Sources, Part A: Recovery, Utilization, and Environmental Effects</i> (Taylor & Francis)	3
Liebersbach et al. [90]	2021	Evaluation of the feasibility of a heat recovery system from greywater from showers and backwater from pool filters for an indoor swimming pool	<i>Energies</i> (MDPI)	2
Salama and Sharqawy [91]	2020	Evaluation of the thermal performance of drain water heat recovery units through experimental studies under steady operating conditions	<i>Applied Thermal Engineering</i> (Elsevier)	6
Murr et al. [92]	2020	Parametric analysis of the performance of a new multi drain heat recovery system using greywater from different devices simultaneously	<i>Energy and Buildings</i> (Elsevier)	4
Kordana et al. [93]	2019	Analysis of key factors affecting the development of drain water heat recovery systems and identification of the strengths and weaknesses of these systems	<i>Resources</i> (MDPI)	19
Spriet and McNabola [94]	2019	Assessing the impact of implementing heat recovery systems from drain water in commercial kitchens in the UK using a financial criterion	<i>Energy and Buildings</i> (Elsevier)	13
Spriet and McNabola [95]	2019	Presentation of a probabilistic method for predicting heat consumption and its use to test the operation of the drain water heat recovery system	<i>Energy and Buildings</i> (Elsevier)	10
Ip et al. [96]	2018	Evaluation of the environmental and financial sustainability of a vertical waste-water heat exchanger on the example of the installation at Sport Pavilion	<i>Environmental Science and Pollution Research</i> (Springer)	12
Akbarzadeh et al. [97]	2018	Presentation of a new computational approach to the numerical study of the thermal characteristics of vertical drain water heat recovery units	<i>Heat Transfer Research</i> (Begell House)	6

* Number of citations according to the Web of Science database (as of 30 September 2022).

Figure 3 presents the keywords co-occurrence maps of greywater energy recovery papers, which were generated using the VOSviewer software. Both Author Keywords and Keywords Plus from Web of Science were included in the analysis. Both of these groups of keywords are useful for studying the structure of knowledge in a scientific field [98]. The size of nodes in the network is determined by the frequency of occurrence of the given keyword. The distance between the nodes indicates the frequency of co-occurrence of two keywords (the closer the nodes are to each other, the greater the correlation between them). And the thickness of the lines connecting nodes indicates the frequency of occurrence of two keywords in publications.

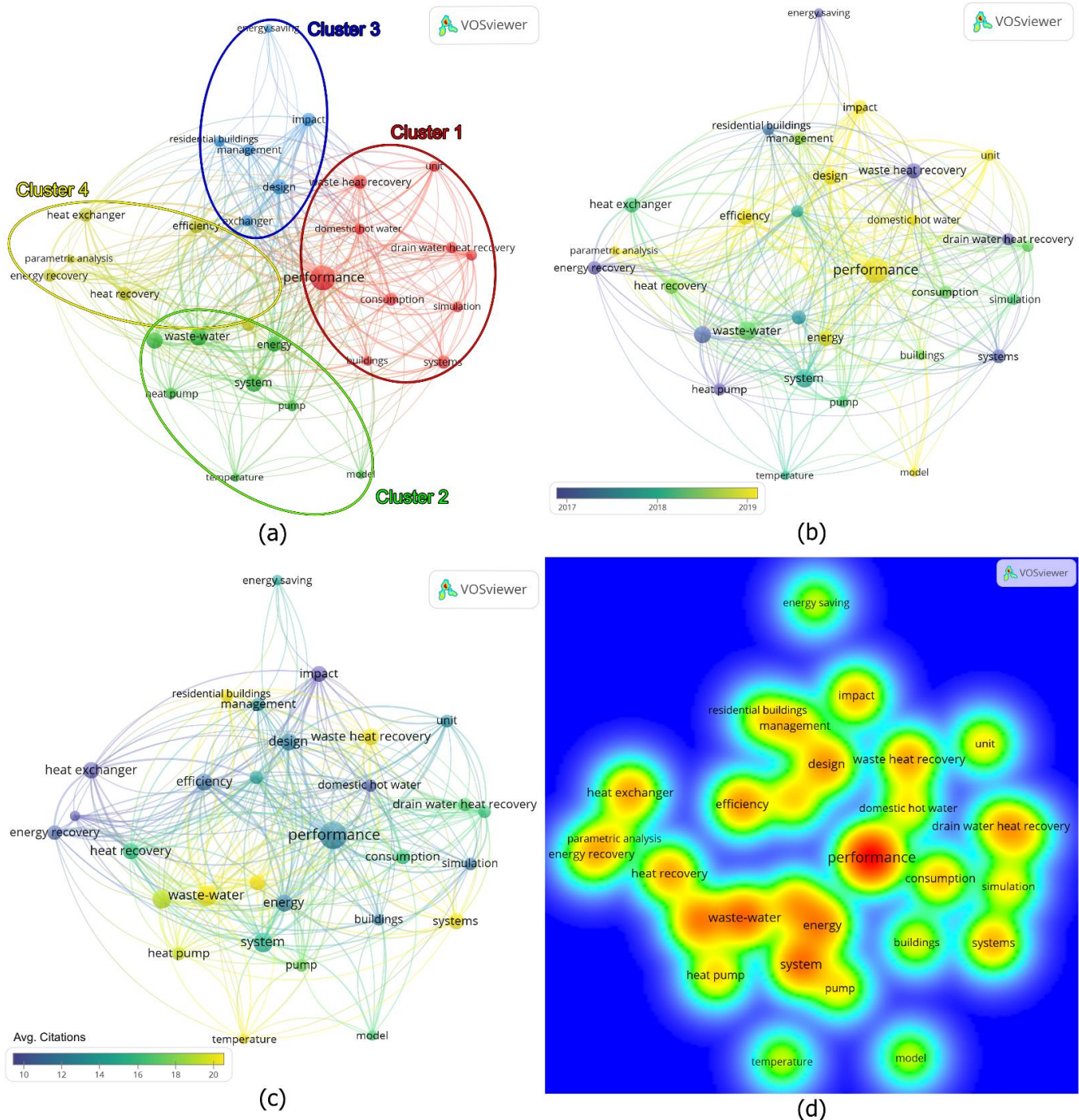


Figure 3. The keywords co-occurrence network of greywater energy recovery papers: (a) Clusters distributions; (b) Timeline of occurrences, (c) Average number of citations; (d) Density view.

In addition, Table 5 summarizes the most important information on the assignment of keywords to clusters, total link strength, occurrences, and the average number of citations. There were a total of 422 different keywords in the publications. Due to their large number, the analysis was limited to those keywords that appeared in at least five articles. This reduced the number of expressions to 30. The keywords and the nodes representing them were divided into four clusters. Each of them was assigned a different color on the map (Figure 3a). Most keywords (10) were assigned to cluster 1, marked on the map in red. Subsequent clusters were assigned numbers in the order corresponding to the number of assigned elements. Therefore, the cluster number does not reflect the total number of

connections and their strength. The individual keywords were connected by 296 lines with a total link strength of 601. It is worth noting that the values describing the number and strength of links are assigned to each keyword individually. Therefore, the total number of links resulting from the data presented in Table 5 is twice as high as for the entire network.

Table 5. The most popular keywords in greywater energy recovery domain.

Keyword	Cluster	Links	Total Link Strength	Occurrences	Average Citations
buildings	1	16	23	6	12.0
consumption	1	17	33	9	16.0
domestic hot water	1	21	38	7	10.4
drain water heat recovery	1	16	22	8	16.6
optimization	1	20	33	7	16.1
performance	1	29	111	27	12.4
simulation	1	18	27	7	11.9
systems	1	18	30	10	28.0
unit	1	17	33	7	12.9
waste heat recovery	1	22	41	11	24.0
energy	2	23	53	12	12.2
energy efficiency	2	21	36	14	18.8
heat pump	2	19	29	8	19.1
model	2	10	14	5	16.4
pump	2	19	36	7	17.3
system	2	24	65	15	15.1
temperature	2	14	19	5	21.2
waste-water	2	27	74	16	21.1
design	3	28	62	12	12.3
energy saving	3	7	7	5	14.2
exchanger	3	22	35	8	13.8
impact	3	22	49	10	5.6
management	3	20	30	8	13.3
residential buildings	3	21	35	7	33.3
drain water	4	24	50	10	20.3
efficiency	4	26	70	12	11.5
energy recovery	4	17	32	9	10.9
heat exchanger	4	16	28	11	7.8
heat recovery	4	21	58	11	15.9
parametric analysis	4	17	29	5	8.6

The analysis showed that the keyword “performance” has the highest total link strength. It appeared in 27 publications, making 29 links with a total link strength of 111 with the other elements on the map. The word “waste-water” came in second place with a total link strength of 74, followed by such elements as “efficiency”, “system”, and “design”. This proves that research in the greywater energy recovery domain places great emphasis on improving the efficiency of dedicated systems and developing new heat exchanger designs. By contrast, analyzing the average number of citations, it can be seen that the phrase “residential buildings” is the most popular, appearing in only 7 publica-

tions. This reflects a significant interest in the use of sustainable energy technologies at the residential level and indicates the need for further research in this area.

The research was further extended by analyzing Author Keywords appearing in articles on greywater energy recovery. This is because they are more comprehensive in presenting the content of the article [98]. The results of the analysis are shown in Figure 4.

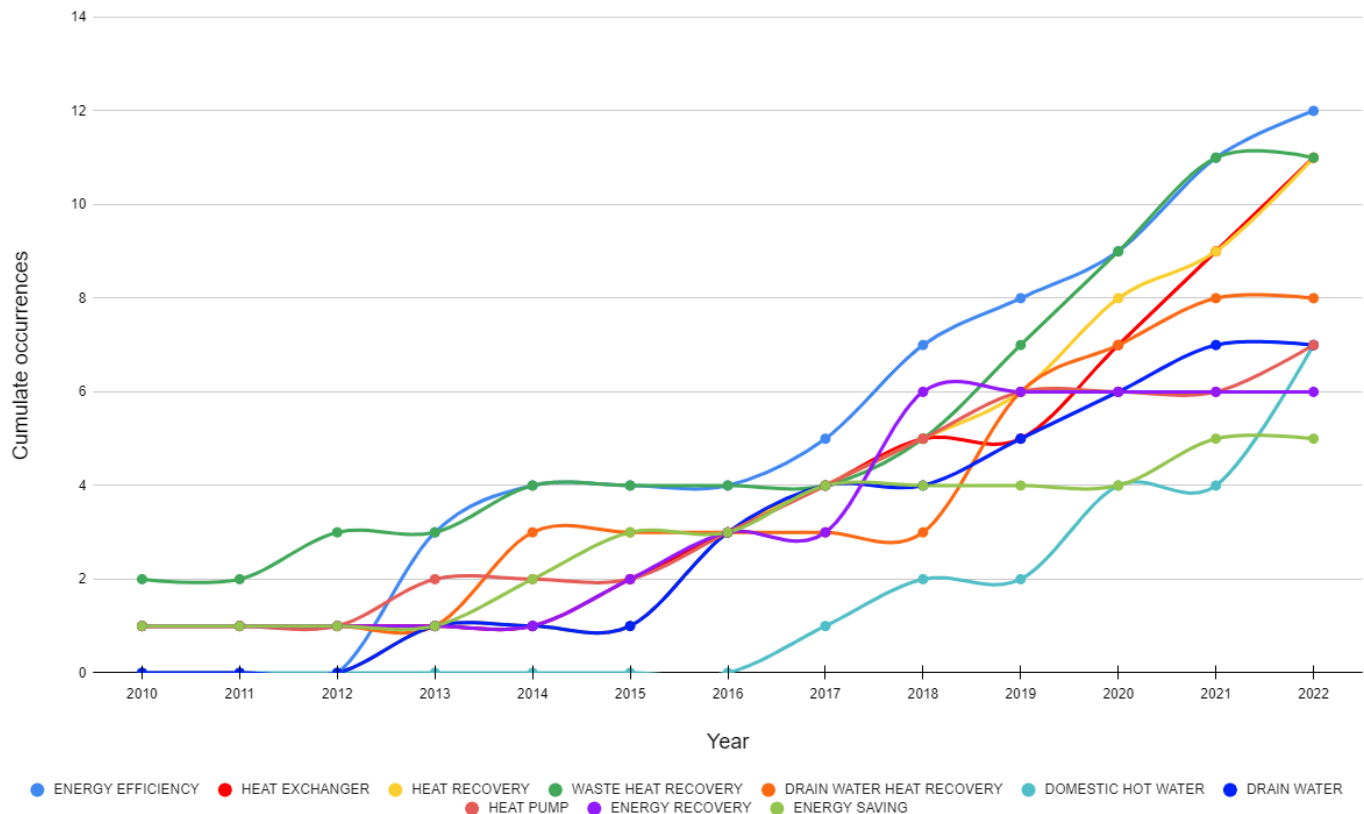


Figure 4. Author Keywords analysis for greywater energy recovery domain.

The phrase that appears most often is “energy efficiency.” It was used for the first time in 2013 and had been appearing regularly in subsequent publications since then. This is a positive trend, probably stemming from the need to meet environmental goals. Economic and political issues are also important motivators for improving the energy efficiency of heat recovery systems, as improving system efficiency, and reducing energy consumption make it possible to reduce dependence on energy imports, thus contributing to the implementation of SDG 7. However, it is worth noting that the keyword “energy efficiency” has replaced the term “energy saving” in publications. Therefore, energy conservation alone is not currently an indicator of sustainability. It should go hand in hand with process optimization. Only slightly fewer occurrences were recorded for the phrases “waste heat recovery”, “heat recovery”, and “heat exchanger”. The phrases “drain water heat recovery” and “energy recovery” were also among the most frequently used Author Keywords. All these keywords refer to the issue of recovering the energy carried by greywater. Among them, the phrase “heat exchanger” has seen the highest growth in recent years. This demonstrates the need to develop new systems for energy recovery from greywater. The new DWHR units should be characterized by high efficiency of heat recovery, and their design should allow for installation in all conditions, regardless of the purpose of the building and the configuration of internal installations. Among the most popular keywords was also the term “domestic hot water”, which was used for the first time in 2017. It can be concluded that the increased interest in technologies that allow the

reduction of energy consumption for water heating is a consequence of the growing share of DHW preparation in the total energy consumption of buildings.

As part of the research, global geographic distributions of publications in the greywater energy recovery domain were also analyzed (Figure 5). The analysis showed that the largest number of publications were developed in countries such as Canada, Poland, the United States, and China. Western European countries, including France, the UK, Switzerland, and Spain, also have a relatively large number of publications. In contrast, there is a noticeable lack of interest in this subject in South American countries and most African countries. The exception is Lebanon.

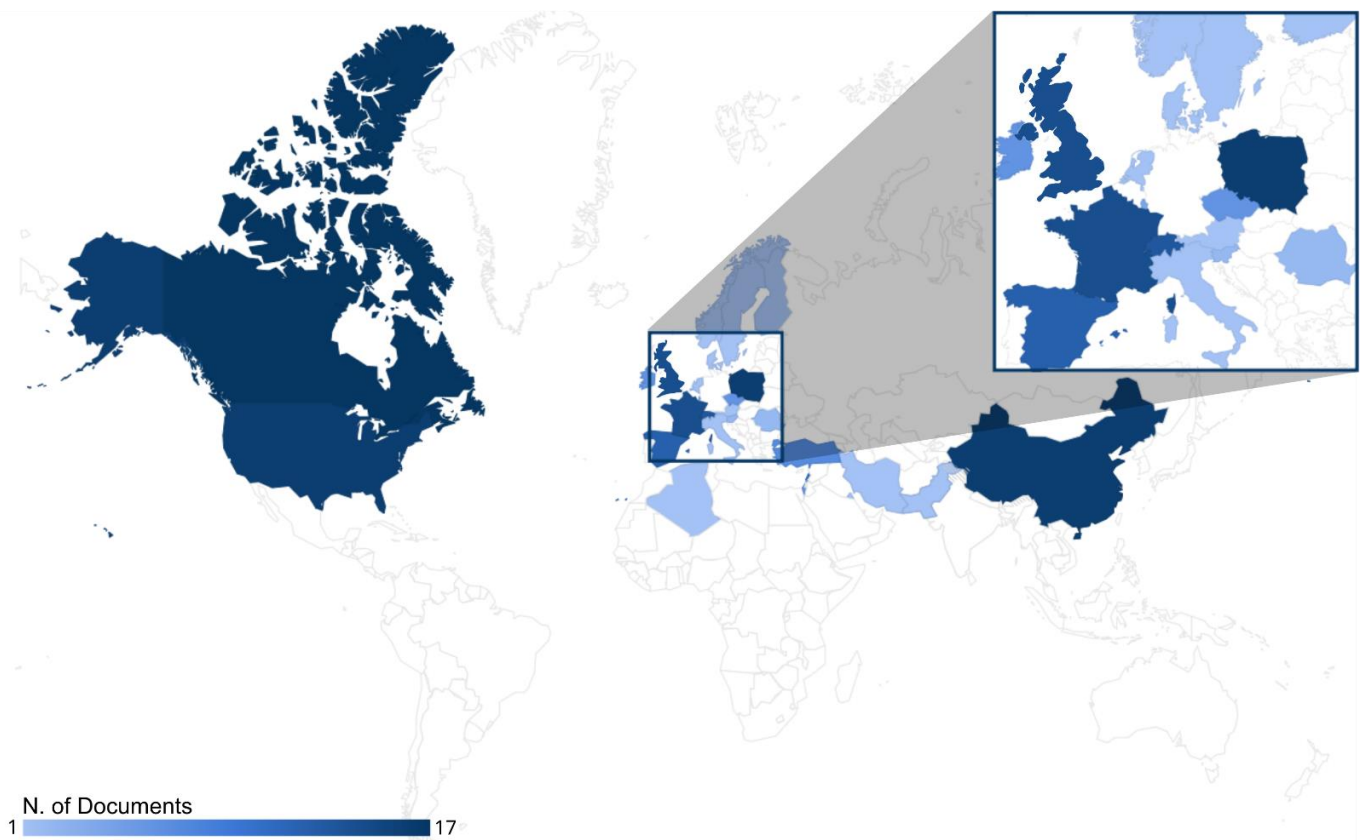


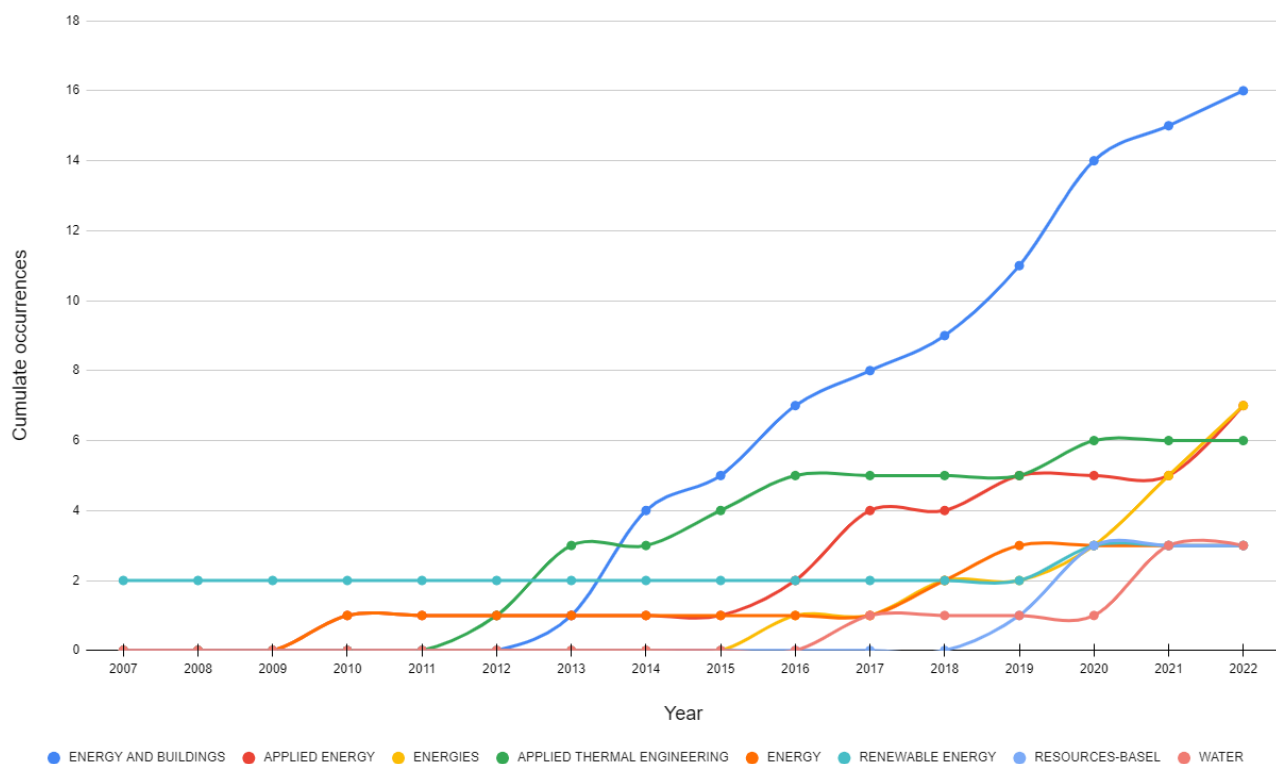
Figure 5. Global geographic distributions of publications in greywater energy recovery domain during the period from 2001 to 2022.

The next stage of the analysis was the identification of the most productive journals in the greywater energy recovery domain. Table 6 lists journals with more than 5 articles published in this subject area. And Figure 6 shows the number of publications in the top eight journals. The largest number of articles (16) was published in the journal *Energy and Buildings*. In this case, the first article was published in 2013, and more are published every year. Second place was taken by the journal *Applied Energy*, which also has a high total number of citations. However, it is worth noting that almost half of this value represents citations of a single article, which was published in 2010 and is one of the most cited publications in the set (Table 7). The same number of papers were published in the journal *Energies*. However, these are more recent publications. Most of them were published after 2020. Thus, *Energies* is now becoming a leader in promoting the idea of energy recovery from greywater. The list in Table 6 ends with the journal *Applied Thermal Engineering*, where most of the articles are from before 2017. Other journals published up to three papers on greywater energy recovery.

Table 6. The most productive journals in greywater energy recovery domain.

Journal (Publisher)	Number of Papers	Total Number of Citations *	Cite Score 2021	Journal Impact Factor 2021	Category Quartile (WoS)
<i>Energy and Buildings</i> (Elsevier)	16	245	11.5	7.201	Q1
<i>Applied Energy</i> (Elsevier)	7	222	20.4	11.446	Q1
<i>Energies</i> (MDPI)	7	51	5.0	3.252	Q3
<i>Applied Thermal Engineering</i> (Elsevier)	6	150	10.7	6.465	Q1/Q2

* Number of citations according to the Web of Science (WoS) database (as of 30 September 2022).

**Figure 6.** Publications in greywater energy recovery domain in the top eight journals.

In addition, the three-field plot, which is often used in bibliometric analyses, was developed using Bibliometrix software. The Sankey diagram presented in Figure 7 shows the relations between countries, authors, and keywords of publications on greywater energy recovery research. The maximum number of elements in each field is 20. The individual elements of the diagram are illustrated by rectangles of different colors. Their height relates to the sum of the relationships between the elements.

Figure 7 also shows links made between the elements. For example, research by authors from Switzerland, a country with some of the most influential research topics, focuses mainly on energy efficiency, DHW preparation, energy recovery, and the use of heat pumps. Based on Figure 7, it is also possible to assess in which parts of the world research is being carried out on the topic. For example, research related to falling film drain water heat recovery units is mainly carried out by authors from Canada.

Table 7. The most cited research papers on greywater energy recovery.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Frijns et al. [99]	2013	A quantitative overview of the possibilities to recover and produce energy from the water cycle	<i>Energy Conversion and Management</i> (Elsevier)	140
Wong et al. [26]	2010	Assessing the potential for heat recovery using simple horizontal heat exchangers installed beneath the shower drain in high-rise residential buildings in Hong Kong	<i>Applied Energy</i> (Elsevier)	106
Liu et al. [100]	2010	Presentation of the applicability of an exhaust heat recovery system in public shower facilities. The proposed solution consists of three sections, including a shower water heat recovery system	<i>Energy</i> (Elsevier)	72
McNabola and Shields [101]	2013	Analysis of the efficiency of a horizontal shower water heat recovery system and evaluation of the potential economic benefits	<i>Energy and Buildings</i> (Elsevier)	53
Bertrand et al. [102]	2017	Proposal for a method to quantify the cost of energy in a building and the potential for energy savings at the city scale through the use of in-building greywater heat recovery systems	<i>Applied Energy</i> (Elsevier)	40

* Number of citations according to the Web of Science database (as of 30 September 2022).

The diagram shown in Figure 7 further assesses the extent of international cooperation in the field of greywater energy recovery. It is clear that the authors representing the countries with the highest number of relationships (Poland, Switzerland, Canada) do not establish international cooperation in their research. The situation is different in the case of authors from France, Lebanon, the United States, or China.

3.2. Greywater Recycling

Global freshwater consumption for agricultural, industrial, and municipal purposes has increased nearly sixfold since 1900, with a marked slowdown since 2000 [103]. For buildings, water consumption and its variability over time are determined by a number of factors, including the type of building, the type of plumbing fixtures and appliances installed, as well as weather conditions [104,105]. As a result of water consumption, significant amounts of wastewater are produced, of which about 40% [106] to as much as 80% [107] and more [108] is greywater. Studies show that GW reuse can reduce unnecessary disposal of water resources and provide an alternative source of water in water-stressed areas [109]. Reducing drinking water consumption can also contribute to minimizing the amount of wastewater produced in the city [110]. In addition, Safarpour et al. [111] indicate that technologies to reduce wastewater production are a sustainable option in terms of economic and social aspects.

Publications dealing with greywater recycling appeared as early as the beginning of this millennium [112], as indicated by Figure 8. The first papers addressed the issue of using greywater as an alternative water source in single-family houses or small public buildings [113]. In the case of articles published at the beginning of the 21st century, there is a tendency to treat greywater recycling as a form of water conservation in underdeveloped countries with a significant share of people living under international poverty lines [114].

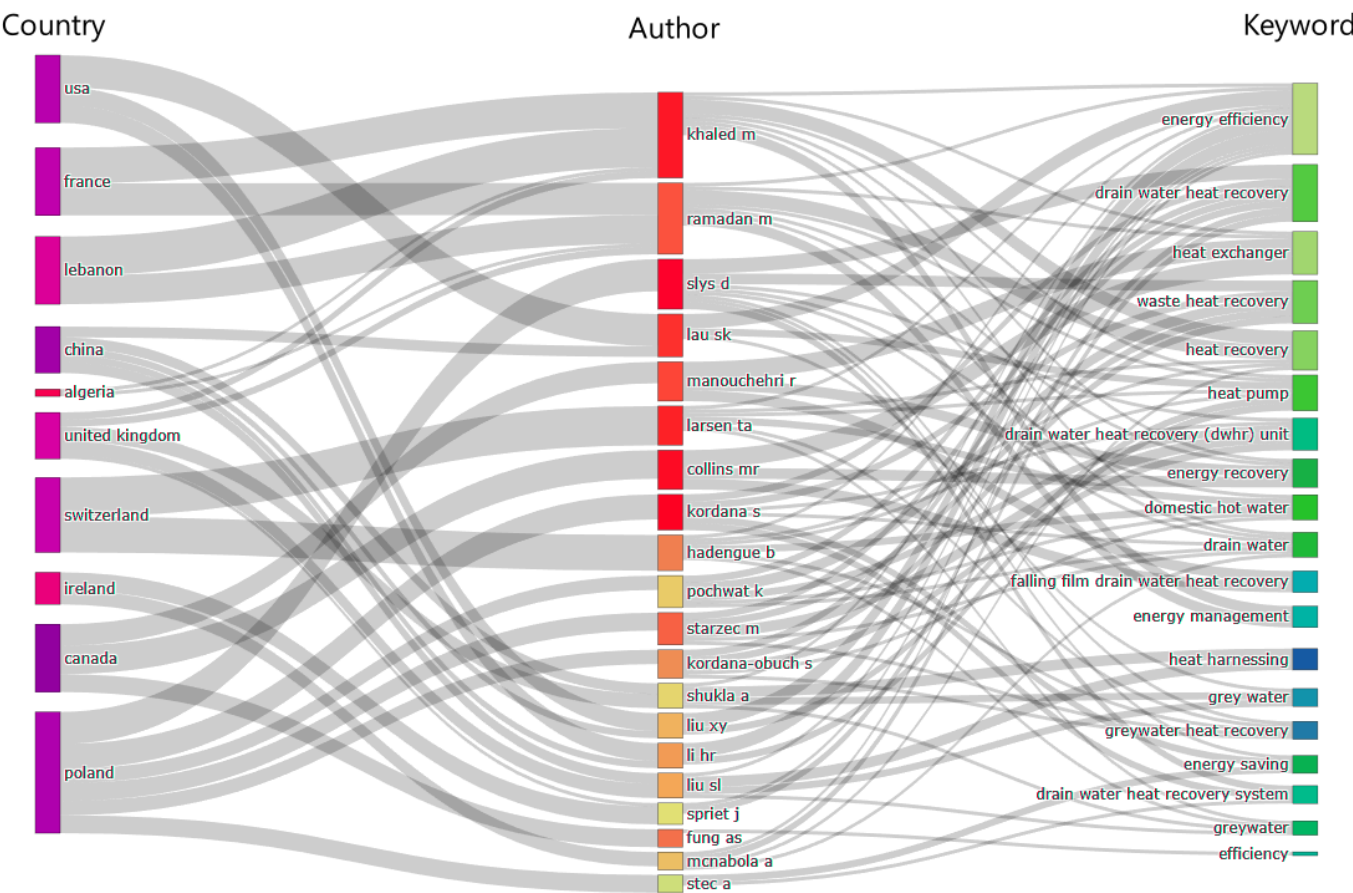


Figure 7. Sankey diagram for greywater energy recovery research.

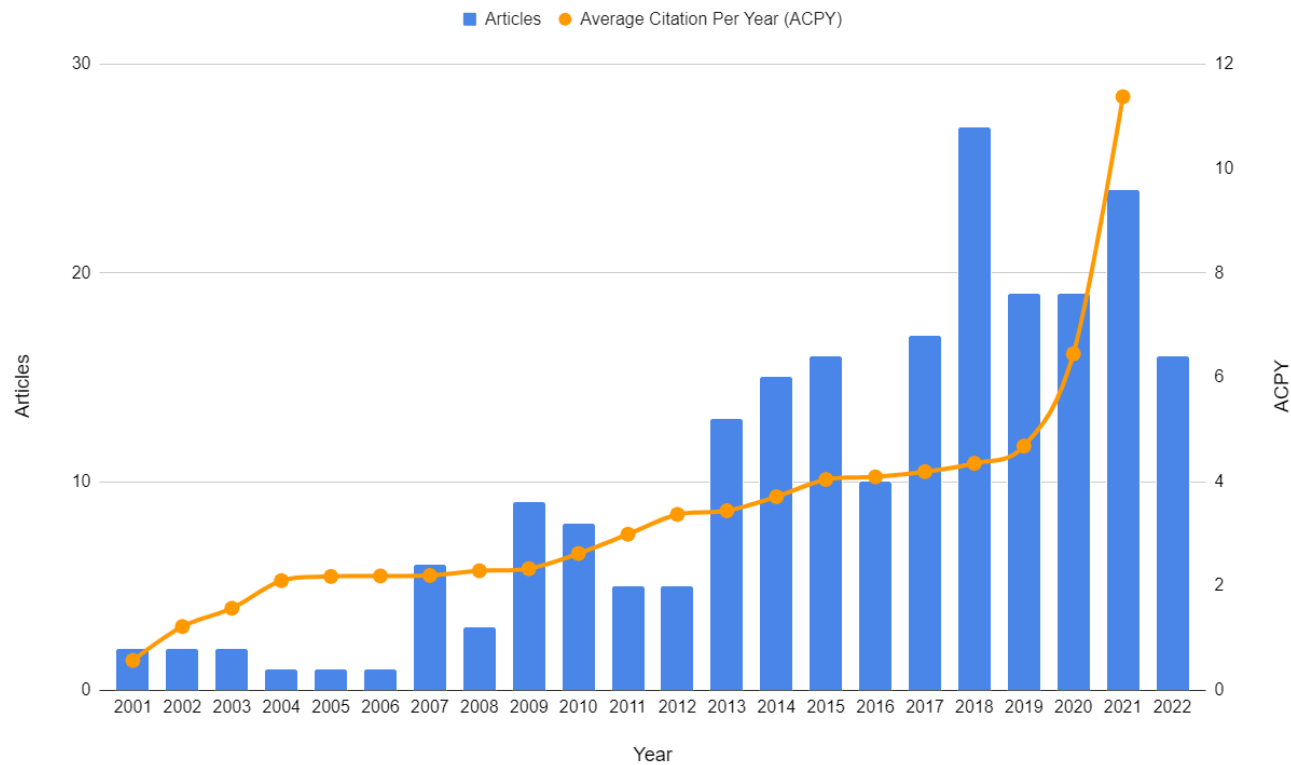


Figure 8. Publication trend in greywater recycling domain.

The increased interest in the topic of greywater recycling resulted in increased awareness of the risks associated with the use of greywater and the resulting sanitation requirements [115]. An often-discussed aspect of greywater recycling was the financial profitability of greywater collection and storage facilities [116]. The financial viability of GWRs was the factor determining the comparison of these systems to rainwater harvesting systems and the analysis of how the two systems could work together to maximize water savings [117,118]. It is worth noting that publications addressing these issues are among the most cited papers in the greywater recycling domain (Table 8). In the following years, there was also a discussion of public attitudes toward greywater reuse. Such publications were mainly based on surveys of community groups using greywater recycling systems or considering this solution in their place of residence [119]. Further interest in the topic resulted in publications addressing the implementation of greywater recycling techniques with consideration of minimizing investment costs [120]. In recent years, greywater recycling has received a lot of attention from both researchers and potential users. Publications that have appeared in the last few years focus on both the social attitudes regarding the use of greywater [10] and the economic aspect of GWRs implementation [121,122]. Thus, these topics are still relevant. However, more and more authors are focusing on environmental and legal issues. Table 9 shows selected publications from the last five years, along with the number of citations according to the Web of Science database.

Table 8. The most cited research papers on greywater recycling.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Al-Jayyousi [123]	2003	Assessment of the role of greywater reuse in sustainable water management in arid regions. Presentation of experience from Jordan	<i>Desalination</i> (Elsevier)	235
Friedler and Hadari [116]	2006	Analysis of the economic feasibility of model on-site greywater reuse systems in multi-story buildings	<i>Desalination</i> (Elsevier)	182
Ghisi and Ferreira [117]	2007	Evaluation of potential potable water savings by using rainwater and/or greywater in a multi-storey residential building in southern Brazil	<i>Building and Environment</i> (Elsevier)	145
Ghisi and de Oliveira [118]	2007	Evaluation of potential potable water savings by using rainwater and/or greywater in two homes in southern Brazil	<i>Building and Environment</i> (Elsevier)	112
Domènech and Saurí [124]	2010	Study of the perceptions of 120 greywater users in the Barcelona metropolitan area. Assessment of institutional, technical, and economic challenges in the context of socioeconomic changes	<i>Resources, Conservation and Recycling</i> (Elsevier)	98

* Number of citations according to the Web of Science database (as of 30 September 2022).

Figure 9 presents the keywords co-occurrence maps of greywater recycling papers that were generated using the VOSviewer software. On the other hand, Table 10 shows the keywords that make up the clusters and their assignment to each group. A total of 1009 keywords were analyzed. As was the case with the analysis of publications on energy recovery from greywater, the analysis was limited to those keywords that appeared most frequently in the papers. Due to having more than twice as many records, the minimum number of occurrences of a keyword (Author Keyword or Keyword Plus) was assumed to be 10. As a result, the number of keywords was reduced to the 32 most common phrases. As with the papers in the greywater energy recovery domain, the keywords were divided into 4 clusters, with each cluster represented by a different color on the map (Figure 9a). The largest number of keywords (13) were assigned to cluster 1, marked in red. Cluster 2 (green) was assigned 11 keywords. There are 5 phrases in cluster 3 (blue), while 3 keywords were assigned to cluster 4 (yellow). The nodes representing the keywords were connected by 380 links with a total link strength of 1241.

Table 9. Selected research papers from the last five years in greywater recycling domain.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Gómez-Monsalve et al. [125]	2022	Analysis of the environmental performance of a hybrid system based on greywater recycling and rainwater harvesting, and its comparison with a centralized system for a building with high water consumption	<i>Journal of Cleaner Production</i> (Elsevier)	3
Portman et al. [126]	2022	A survey of public opinion on the use of three alternative water sources: greywater, air conditioner condensate, and rainwater	<i>Water Reuse</i> (IWA Publishing)	1
Amaris et al. [127]	2021	Providing evidence on greywater use preferences and heterogeneity of choices	<i>Resources, Conservation and Recycling</i> (Elsevier)	5
Arden et al. [128]	2021	Evaluation of four types of systems in terms of their ability to meet non-potable water demand as well as environmental and financial efficiency	<i>Water Research</i> (Elsevier)	4
Suchorab et al. [122]	2021	Evaluation of the profitability of dual installations in a hotel	<i>Applied Water Science</i> (Springer)	0
Radingoana et al. [129]	2020	Analysis of the feasibility of reusing greywater for home gardening	<i>Physics and Chemistry of the Earth</i> (Elsevier)	14
Rodríguez et al. [108]	2020	Determination of water consumption habits and the amount of generated greywater based on surveys	<i>Water</i> (MDPI)	9
Byrne et al. [130]	2020	Presentation of conclusions resulting from the operation of three single-family buildings designed with particular emphasis on effective water management	<i>Water</i> (MDPI)	4
Shanableh et al. [24]	2020	Assessment of key challenges and opportunities arising from the implementation of the program mandating the installation of a greywater reuse system	<i>Desalination and Water Treatment</i> (Desalination Publications)	4
Batisha [106]	2020	Analysis of how the use of greywater can contribute to sustaining mega urban projects	<i>Environmental Science and Pollution Research</i> (Springer)	2
da Silva et al. [131]	2019	Evaluation of various sources of water reuse, including greywater, rainwater and water from air conditioning system, and a proposal for ways to reduce potable water consumption in an example building	<i>Sustainable Cities and Society</i> (Elsevier)	12
Zhu et al. [132]	2018	Analysis of the potential for greywater use in China and opportunities to increase greywater use rates; presentation of recommendations on the use of greywater for flushing toilets	<i>Journal of Water Reuse and Desalination</i> (IWA Publishing)	28
Wanjiru and Xia [133]	2018	Presentation of two control strategies aimed at ensuring reliable operation of greywater recycling system and rainwater harvesting system with efficient use of associated energy	<i>Journal of Cleaner Production</i> (Elsevier)	28

Table 9. Cont.

Authors	Year	Purpose of the Paper	Journal (Publisher)	Citations *
Shafiquzzaman et al. [134]	2018	Development of a framework based on greywater reuse indicators to assess consumer perceptions	Water SA (Water Research Commission)	8
Taemthong [135]	2018	Evaluation of three ways to recycle greywater from sinks for toilet flushing	Journal of Green Building (College Publishing)	5

* Number of citations according to the Web of Science database (as of 30 September 2022).

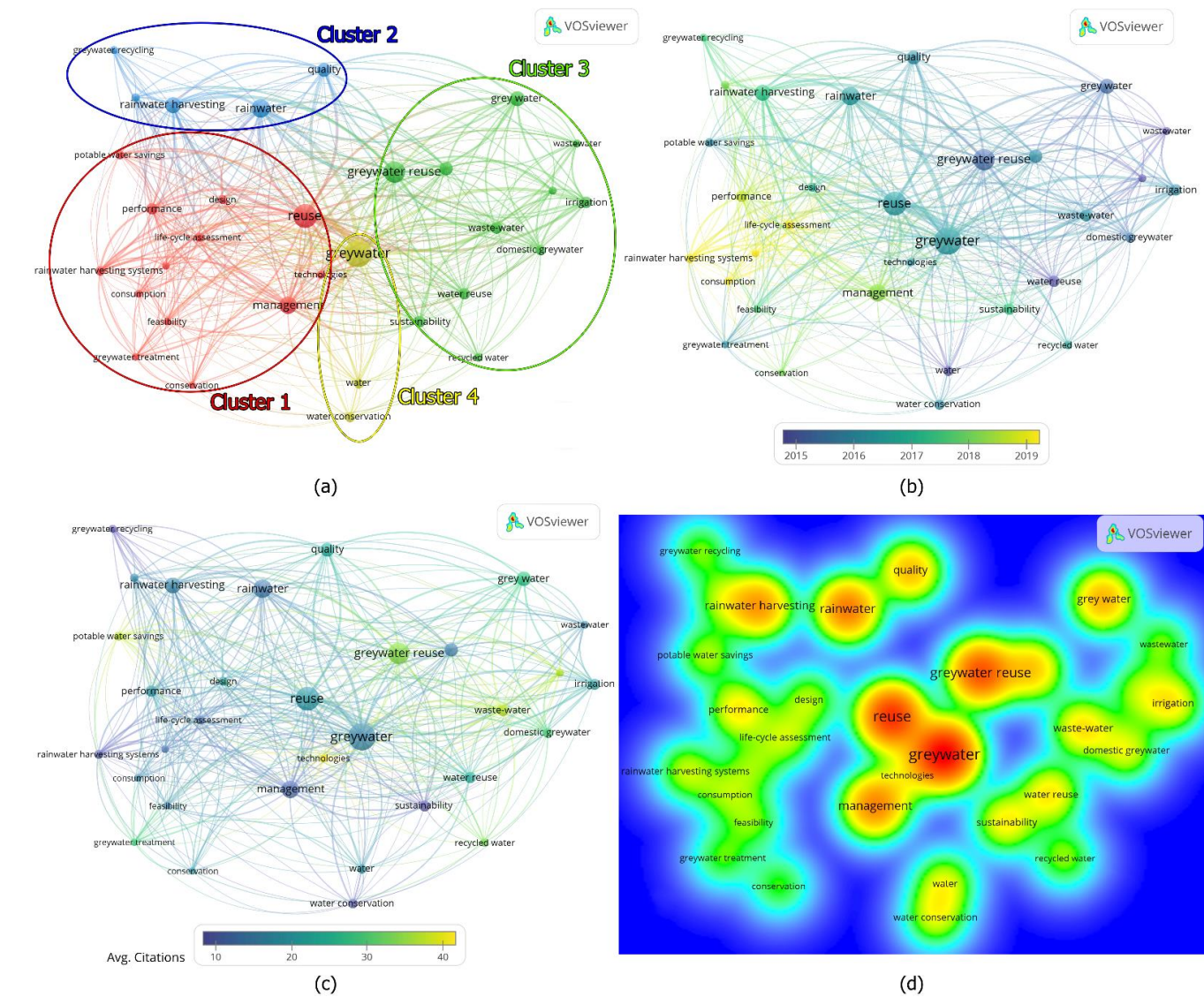


Figure 9. The keywords co-occurrence network of greywater recycling papers: (a) Clusters distributions; (b) Timeline of occurrences (c) Average number of citations; (d) Density view.

Table 10. The most popular keywords in greywater recycling domain.

Keyword	Cluster	Links	Total Link Strength	Occurrences	Average Citations
conservation	1	18	39	10	19.2
consumption	1	21	36	10	16.1
design	1	23	45	13	21.9
energy	1	26	54	10	13.9
feasibility	1	24	49	10	16.0
greywater treatment	1	21	48	10	28.6
life-cycle assessment	1	28	60	13	13.2
management	1	31	141	38	12.8
performance	1	28	93	20	19.1
potable water savings	1	20	44	13	36.2
rainwater harvesting systems	1	23	73	14	10.7
reuse	1	31	221	62	19.6
technologies	1	28	44	11	47.8
domestic greywater	2	22	61	16	29.1
grey water	2	20	84	29	27.2
greywater reuse	2	29	131	52	33.3
irrigation	2	23	83	19	20.5
microbial quality	2	22	48	11	35.6
recycled water	2	15	32	12	32.3
sustainability	2	24	66	19	9.5
systems	2	27	88	25	15.5
waste-water	2	24	78	21	36.2
wastewater	2	20	47	11	16.9
water reuse	2	26	69	20	23.2
greywater recycling	3	16	36	11	6.6
quality	3	27	91	27	22.7
rainwater	3	28	131	41	14.5
rainwater harvesting	3	25	116	33	16.9
savings	3	21	55	12	17.3
greywater	4	31	242	77	16.5
water	4	20	43	15	19.1
water conservation	4	18	34	15	10.7

Analysis using the VOSviewer software showed that the most frequently occurring phrase was the keyword “greywater” (cluster 4). It generates 31 links with a total link strength of 242. The second most frequent keyword was “reuse”, with 31 links with a total link strength of 221. The phrases “greywater reuse”, “grey water”, “water”, and “water reuse” were also relatively common. All of these keywords are directly related to greywater recycling and water resource management. Phrases such as “rainwater”, “rainwater harvesting”, and “rainwater harvesting systems” were also among the most frequently used keywords. This proves the considerable interest in the possibilities of using greywater and rainwater together and the significant potential of such combined systems. In addition to keywords directly related to alternative water sources, the phrases “management” and

“performance” often appeared in the publications. This demonstrates the continuous effort to improve the efficiency of GWRs and the concern for their reliable operation throughout their lifetime. Keywords related to the quality of greywater appeared in 38 papers. Thus, even for publications focused on technological and social issues, reference to the quality of the alternative water source is sometimes unavoidable. In addition, “sustainability” is a relatively frequent keyword, indicating that the implementation of the GWRs can contribute to the achievement of the 17 SDGs.

When analyzing the average number of citations per keyword, it can be seen that the most frequently cited keyword (47.8 times on average) is the phrase “technologies”, despite the relatively low number of occurrences, equal to 11. A high average number of citations was also recorded for the phrase “potable water savings”. Therefore, the analysis indicates a significant interest in new tap water conservation techniques that can contribute to ensuring access to water for a wide range of consumers.

As in the case of greywater energy recovery papers, the review was extended with an analysis of Author Keywords (Figure 10). The most common expression is “greywater”. The number of its occurrences is almost twice as high as the next highest-ranked keywords, and the largest increase in its use was recorded after 2017. Keywords such as “greywater reuse”, “reuse”, or “water reuse” are also used relatively often. All these expressions relate directly to the recycling of greywater. The phrases “rainwater harvesting” and “rainwater” were also among the Author Keywords with the highest number of occurrences. Single occurrences of these keywords appeared before 2010. This confirms that the potential of the combined use of various alternative water sources was noticed several years ago. However, it is in the last decade that the boom of papers in this field has become apparent. Some authors focus only on these two alternative water sources [136,137], while others analyze more [138]. Phrases such as “sustainability” and “water conservation” were also among the most common Author Keywords. They are characterized by a similar number of occurrences and, starting in 2019, appear regularly in publications in this domain. Thus, the analysis confirmed that the implementation of GWRs can contribute to SDG 6 by reducing potable water consumption and providing access to water.

The review also analyzed the global geographic distributions of publications in the greywater recycling domain (Figure 11). This made it possible to identify the countries that are the most productive in greywater recycling publications. Most papers were published by authors from the United States and the UK. It is worth noting that in these countries a lot of publications on greywater energy recovery have also been developed. This creates opportunities for the authors to collaborate in research on the simultaneous recovery of energy from greywater and its recycling in internal installations of buildings. Chile, China, and Israel followed, with Australia, India, and Brazil close behind. Authors representing all these countries published a total of more than 20 items each. The number of papers prepared in other regions of the world is significantly lower. However, it should be noted that the topic of greywater recycling is taken up by representatives of different nationalities living on different continents. Therefore, it is far more widespread than the topic of greywater energy recovery, despite the fact that energy sustainability issues are currently one of the main research topics. This may be due to the fact that water is essential for life. As a consequence, the need to conserve water resources is familiar to representatives of many communities, regardless of the level of economic development. This need may be a result of water deficits, but it may also be due to an increase in the environmental awareness of the population.

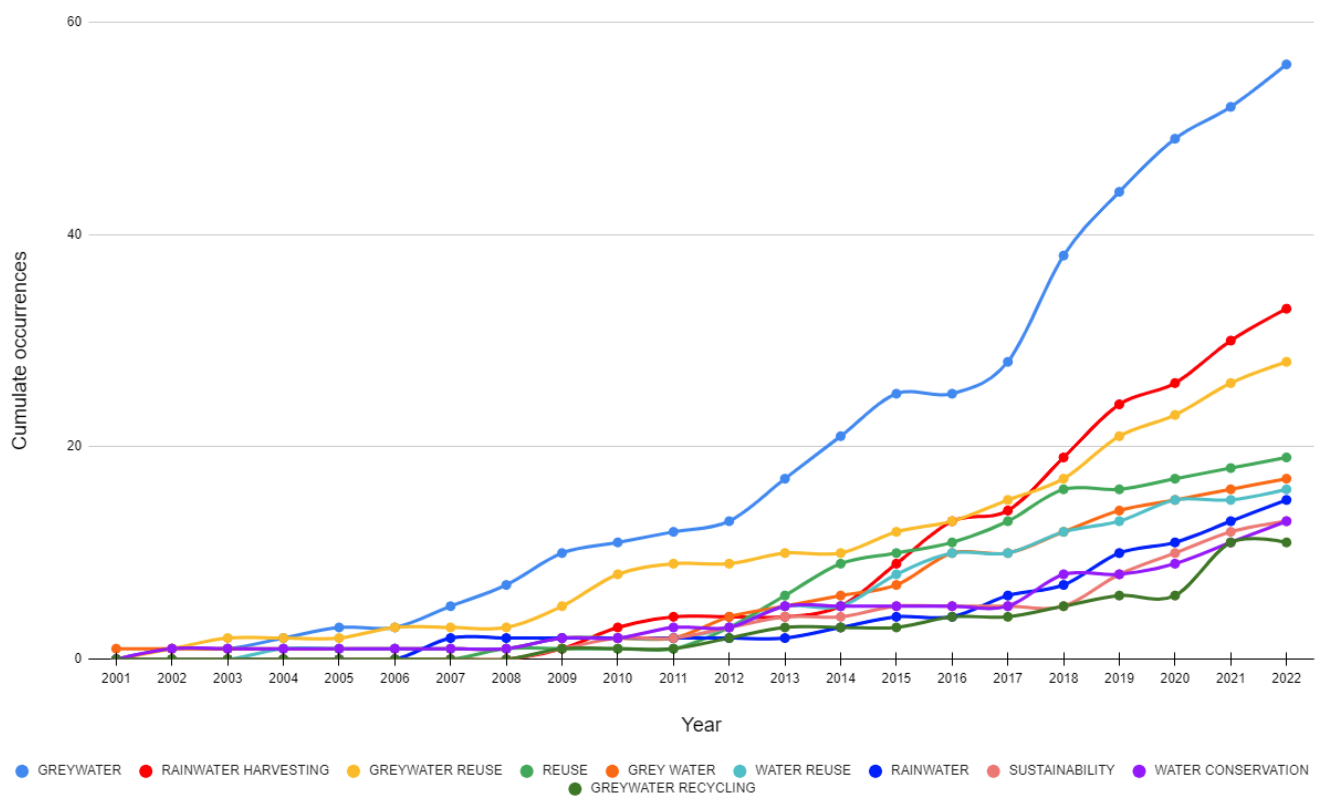


Figure 10. Author Keywords analysis for greywater recycling domain.

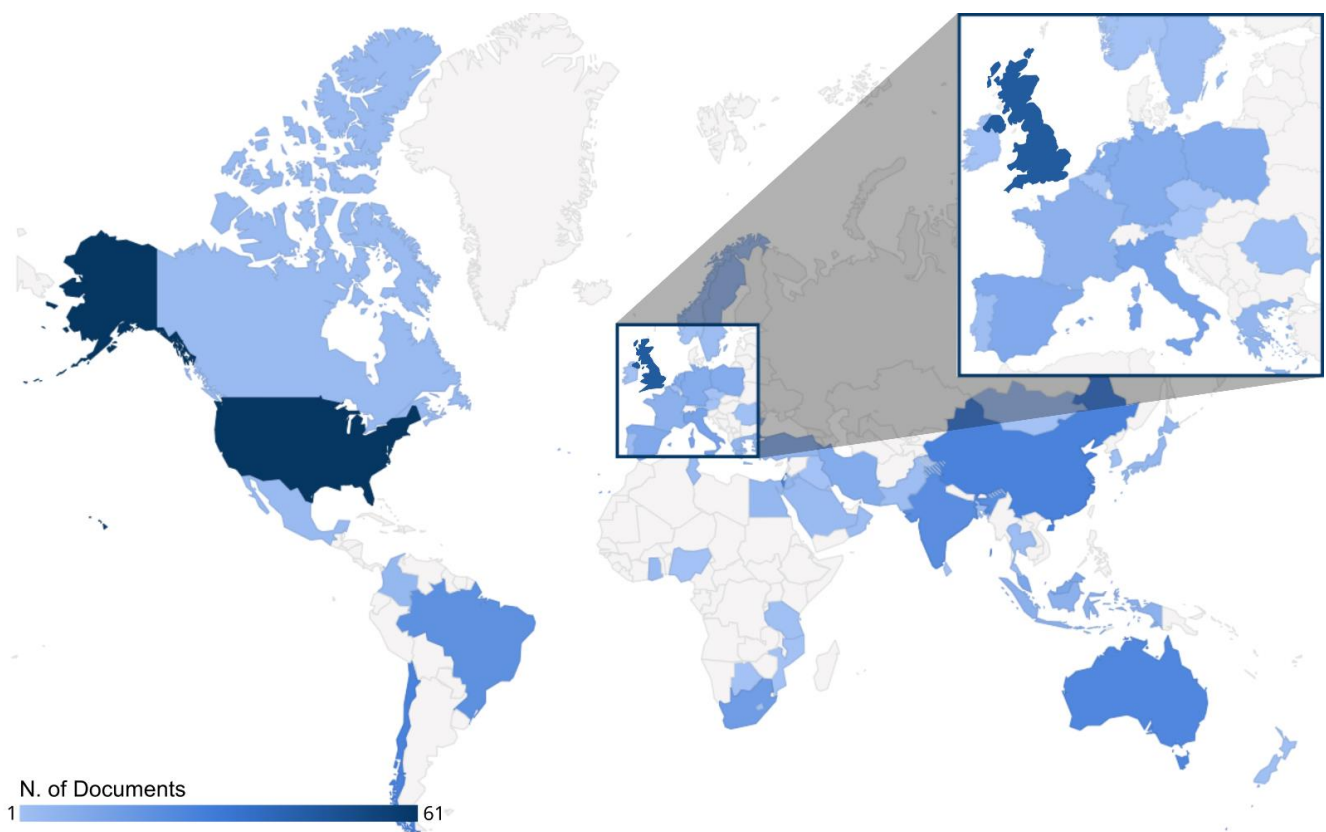


Figure 11. Global geographic distributions of publications in greywater recycling domain during the period from 2001 to 2022.

As in the case of publications in the greywater energy recovery domain, the most productive journals were identified. The results of the analysis are presented in Figure 12 and in Table 11. Due to the significant number of publications, Table 11 lists only those journals with more than 10 papers. The highest number of articles is from *Journal of Cleaner Production* (19). The first of them was published in 2011, and after 2013 there was a rapid increase in the number of papers on the subject. This increase was particularly evident in 2018, but the journal also publishes articles on greywater recycling today. Other journals with the highest number of papers on greywater reuse are *Water* and *Water Science & Technology*. However, it should be noted that in the journal *Water Science & Technology*, the first publications were already published at the beginning of the 21st century, while a clear slowdown in the growth of publications can now be observed. The situation is completely different for the journal published by the Multidisciplinary Digital Publishing Institute. The first publication was published in 2012, and in the following years, there was a clear boom in articles on this topic. The list is closed by *Resources, Conservation and Recycling*. For this journal, there is a gradual increase in the number of publications in the greywater recycling domain. On the other hand, an analysis of the total number of citations shows that articles published by Elsevier are the most frequently cited. However, it should be noted that the number of citations of individual publications varies widely. Some of them have been cited more than 50 times, but there are also those that have been cited less than 5 times.

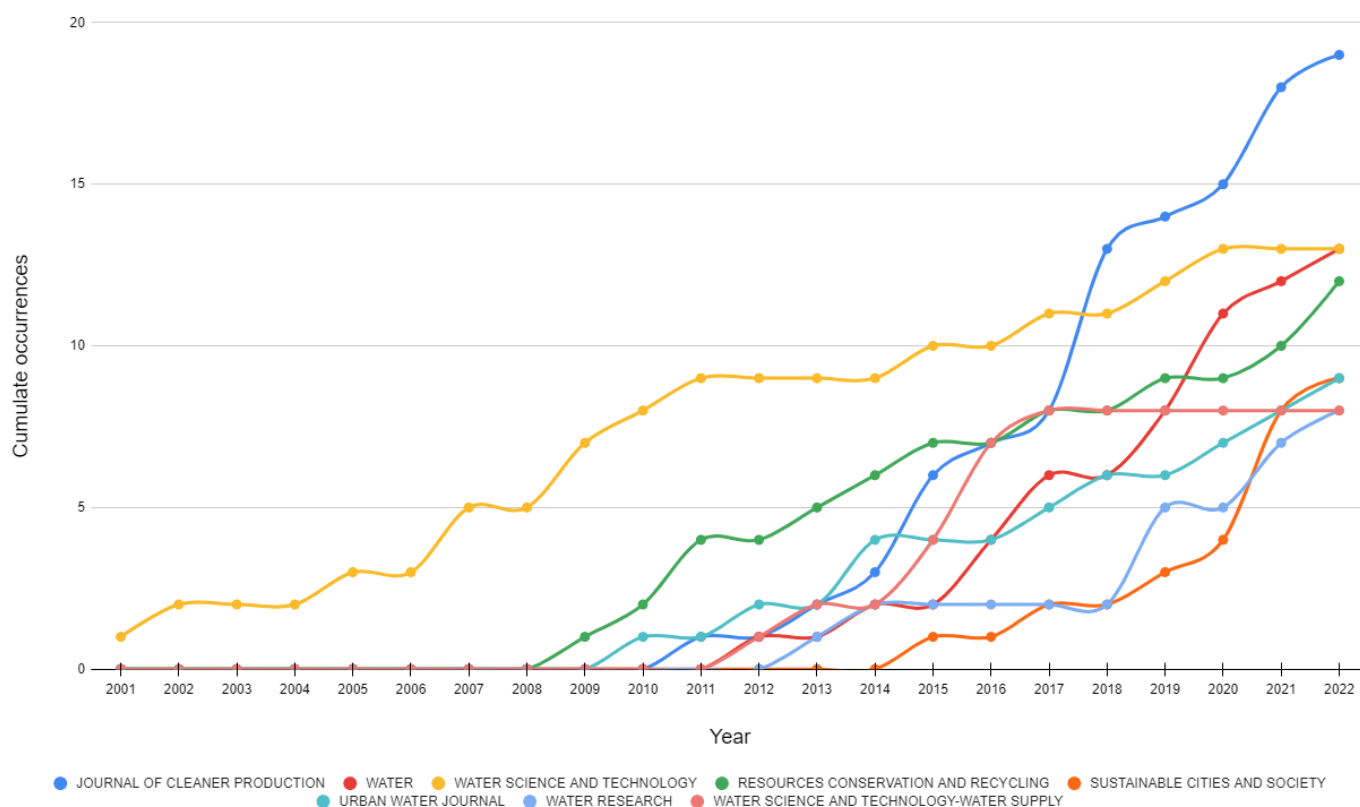


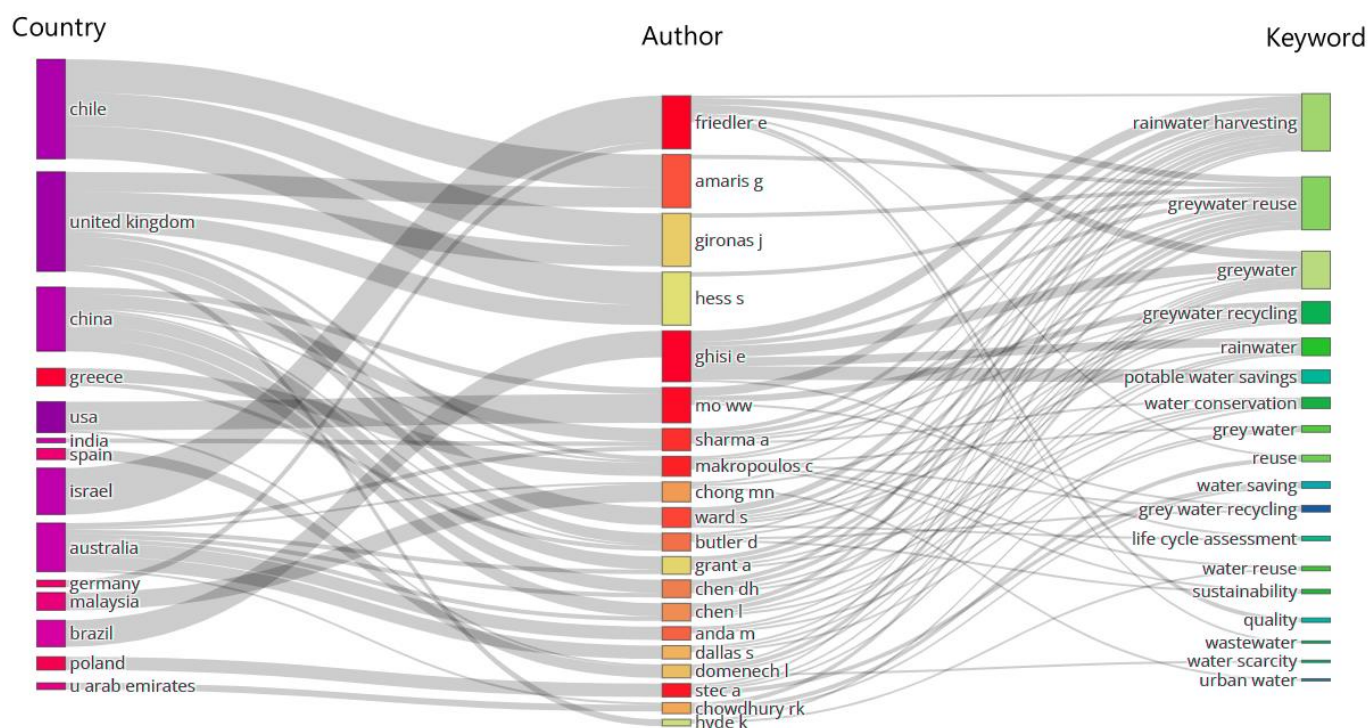
Figure 12. Publications in greywater recycling domain in the top eight journals.

Table 11. The most productive journals in greywater recycling domain.

Journal (Publisher)	Number of Papers	Total Number of Citations *	Cite Score 2021	Journal Impact Factor 2021	Category Quartile (WoS)
<i>Journal of Cleaner Production</i> (Elsevier)	19	476	15.8	11.072	Q1
<i>Water</i> (MDPI)	13	150	4.8	3.53	Q2/Q3
<i>Water Science & Technology</i> (IWA Publishing)	13	266	3.4	2.43	Q3/Q4
<i>Resources, Conservation and Recycling</i> (Elsevier)	12	401	17.9	13.716	Q1

* Number of citations according to the Web of Science (WoS) database (as of 30 September 2022).

The next stage of the analysis was to develop a three-field plot (Figure 13). As in the case of publications in the greywater energy recovery domain, this figure shows the relationships between countries, authors, and keywords within the analyzed database. It was generated assuming a maximum number of elements per field of 20. When analyzing Figure 13, it can be seen that the issue of greywater recycling is being addressed by a larger group of researchers than greywater energy recovery. In addition, it is noticeable that many researchers are willing to cooperate with scientists representing other nationalities. Examples include authors from Chile or the UK. On the other hand, publications by researchers from Poland or Brazil are usually developed within a single country and sometimes even within a single university. This results in the need to expand the scope of international cooperation in order to make better use of the potential and facilities of the various research units and the communities they represent.

**Figure 13.** Sankey diagram for greywater recycling research.

3.3. Greywater Recycling and Energy Recovery

The final stage of the review was to analyze a combined database of publications dealing with greywater energy recovery and recycling. The data, which were summarized

in Table 12, were determined using Bibliometrix software. They clearly show that only 5 publications out of the 308 analyzed address both the issues of energy recovery from greywater and its recycling. These are articles based mainly on financial analysis [139]. The other records focus only on one way of using greywater. It is also notable that the relatively low number of Author Keywords appear in papers from both domains. Especially as both greywater energy recovery and greywater reuse are effective tools for achieving Sustainable Development Goals. Reducing the temperature of greywater not only does not prevent its reuse but may prove beneficial. Oteng-Peprah et al. [38] indicate that the high temperature of greywater promotes the growth of microorganisms and can sometimes also cause the precipitation of inorganic salts. Therefore, the research carried out in the field of greywater recycling should be extended to include energy issues. This applies primarily to the possibility of recovering energy from greywater. However, the issues of energy consumption by GWRs in various operating conditions should not be forgotten. Expanding the spectrum of research on greywater use seems to be a necessity. Only such an approach will be a step towards creating new value for potential users.

Table 12. Basic information on the analyzed groups of publications.

Description	Results		
	Greywater Energy Recovery Papers	Greywater Recycling Papers	Greywater Recycling and Energy Recovery Papers
Documents	91	222	308
Annual Growth Rate, %	6.82	10.41	8.69
Average citation per document	15.23	19.76	18.51
Author's Keywords	268	697	922
Authors	211	599	800
Co-Authors per document	3.58	3.41	3.47
International co-authorships, %	16.68	22.07	21.43

The lack of cooperation between units dealing with the use of greywater for various purposes is also confirmed by the low number of authors with publications in both fields (only 10 people). Meanwhile, authors representing different units can complement each other and share knowledge and skills in the course of their work. The formation of synergies between people representing different universities and even countries would allow the exchange, modification, and consideration of various concepts and their practical applications. As a result, the efficiency of their work would be raised, and the research potential would be strengthened. Carrying out joint research in the domains of greywater energy recovery and recycling could also contribute to an increase in the competitiveness of scientific units.

Harnessing the expertise of people involved in greywater recycling would also be beneficial for greywater energy recovery researchers. Papers dealing with greywater reuse issues are far more likely to be cited. The increased reach of such publications may be due to the greater internationalization of the projects. This approach to conducting scientific research affects its innovativeness and increases its usefulness. In addition, far more researchers devote their time and competence to the issues of greywater recycling, which also affects the interest in publications in this field.

In order to confirm the above thesis, keywords appearing in both groups of publications were analyzed. The results of this analysis are shown in Figure 14. A total of 1329 expressions related to greywater energy recovery and recycling were analyzed. As in the previous case, the analysis was limited to keywords that appeared at least ten times in the publications. This reduced the number of analyzed expressions to 46. In this case, the keywords were assigned to four groups. Cluster 1 includes 15 phrases directly related to greywater energy recovery research. The expressions assigned to clusters 2 and 3 are related to greywater recycling. These groups include 15 and 11 terms, respectively. In

“gray water”. Some authors use the general phrase “waste-water”, which can also make it difficult to find the paper in the database. The second most frequently appearing keyword, as in the case of publications in the greywater recycling domain, was “reuse”, with 38 links with a total link strength of 238. The podium is closed by “greywater reuse”.

When analyzing the average number of citations, it can be seen that publications with keywords such as “technologies” and “potable water savings” are the most frequently cited. Thus, it is confirmed that publications in the greywater recycling domain are of interest to a wider audience. It should also be noted that, as in previous cases, a high average number of citations is rarely associated with a high number of occurrences or high total link strength. This is due to the fact that frequently cited keywords tend to be related to a niche topic in a given research area. Because of the small number of publications on a given topic, existing articles are often used to create a list of references for new papers. In addition, when analyzing the timeline of occurrences network, it can be seen that the map is divided into two areas. Clusters 2 and 3 include keywords that were popular in earlier years. On the other hand, clusters 1 and 4 are assigned phrases that have been the most popular in the last few years. Based on this information, it can be concluded that the topic of greywater energy recovery is gaining popularity and meets the current need to reduce the consumption of natural resources. This should encourage authors to be interdisciplinary and broaden their horizons. Establishing cooperation between researchers representing both domains would provide an opportunity for new publications to reach a larger audience and adapt their topics to contemporary trends.

4. Conclusions

The use of greywater generated in buildings is an effective tool for achieving the SDGs. Among the most popular uses of greywater are energy recovery and recycling. This paper presents the results of a retrospective analysis of selected publications dealing with the issues of greywater energy recovery and greywater recycling. This review provides insight into the use of greywater, paving the way for potential new research. Key findings of the review are detailed below.

- The territorial scope of research carried out in greywater recycling domain is considerably larger than that of greywater energy recovery research. In the latter case, the authors are mainly from North American and European countries. These are regions that focus on environmental protection and climate concerns. On the other hand, research on water-saving opportunities is also carried out in poorer countries, including those suffering from water scarcity.
- This review indicates poor cooperation between different universities, especially in the field of greywater energy recovery. Only a small part of the articles was carried out by international research teams.
- In recent years, there has been a marked increase in the number of publications in both fields. However, more papers are devoted to water conservation than to energy conservation. In addition, research on greywater recycling was carried out already at the beginning of the 21st century. This is probably due to the fact that water is a vital resource that is difficult to obtain in many parts of the world.
- The most influential journals in the greywater energy recovery domain are *Energy and Buildings*, *Applied Energy* and also *Energies*. In the case of articles addressing greywater recycling issues, these are *Journal of Cleaner Production*, *Water*, and *Water Science & Technology*. Thus, articles in both fields are published in prestigious journals with wide coverage. In addition, some of these journals publish in open access, which allows them to reach a wider audience (both researchers and potential users of these systems).
- Conducting collaborative research could benefit both those working on greywater energy recovery and scientists whose research focuses on the possibilities of greywater recycling. Currently, such research is quite rare and is mainly limited to analyses of the profitability of using individual systems. Therefore, the limited transfer of knowledge between these fields provides a potential avenue for future research.

The results of the bibliometric analysis of publications in greywater recycling and greywater energy recovery domains can be a start in the implementation of papers by scientists, as this approach allows for a better understanding of the structure of knowledge in the field. These analyses can also guide those who have been doing research in these fields for some time, pointing out not fully discovered research paths. Although the results do not define a single strategy, they are a valuable contribution to research in the field of greywater energy recovery and recycling. Together with the findings of other researchers and people working on the subject, this review can contribute to the further development of greywater energy recovery systems and greywater recycling systems.

Author Contributions: Conceptualization, S.K.-O.; methodology, S.K.-O. and M.W.; software, M.W.; validation, S.K.-O., M.S. and M.W.; formal analysis, S.K.-O. and M.S.; investigation, S.K.-O., M.S. and M.W.; data curation, S.K.-O., M.S. and M.W.; writing—original draft preparation, S.K.-O. and M.W.; writing—review and editing, S.K.-O.; visualization, M.W.; supervision, D.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the reviewers for their feedback, which has helped improve the quality of the manuscript, and Energies' staff and editors for handling the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. WCED. *Report of the World Commission on Environment and Development: Our Common Future*; Oxford University Press: New York, NY, USA, 1987.
2. United Nations (UN). *The Sustainable Development Goals Report 2021*; United Nations: New York, NY, USA, 2021.
3. Dmytrów, K.; Bieszk-Stolorz, B.; Landmesser-Rusek, J. Sustainable Energy in European Countries: Analysis of Sustainable Development Goal 7 Using the Dynamic Time Warping Method. *Energies* **2022**, *15*, 7756. [\[CrossRef\]](#)
4. Godfrey, S.; Wambugu, M.; Parikh, P.; Tunhuma, F. Validation of the Sustainable Development Goal 6 Monitoring Structures across East and Southern Africa Using Fuzzy Logic Analysis. *Water* **2022**, *14*, 3065. [\[CrossRef\]](#)
5. Sathre, R.; Antharam, S.M.; Catena, M. Water Security in South Asian Cities: A Review of Challenges and Opportunities. *CivilEng* **2022**, *3*, 873–894. [\[CrossRef\]](#)
6. Firoiu, D.; Ionescu, G.H.; Băndoi, A.; Florea, N.M.; Jianu, E. Achieving Sustainable Development Goals (SDG): Implementation of the 2030 Agenda in Romania. *Sustainability* **2019**, *11*, 2156. [\[CrossRef\]](#)
7. Dumitrescu, C.I.; Moiceanu, G.; Dobrescu, R.M.; Popescu, M.A.M. Analysis of UNESCO ESD Priority Areas' Implementation in Romanian HEIs. *Int. J. Environ. Res. Public Health* **2022**, *19*, 13363. [\[CrossRef\]](#)
8. Diaz-Elsayed, N.; Rezaei, N.; Ndiaye, A.; Zhang, Q. Trends in the environmental and economic sustainability of wastewater-based resource recovery: A review. *J. Clean. Prod.* **2020**, *265*, 121598. [\[CrossRef\]](#)
9. Santos, C.; Matos, C.; Taveira-Pinto, F. A comparative study of greywater from domestic and public buildings. *Water Supply* **2014**, *14*, 135–141. [\[CrossRef\]](#)
10. Stec, A.; Słyś, D. Financial and Social Factors Influencing the Use of Unconventional Water Systems in Single-Family Houses in Eight European Countries. *Resources* **2022**, *11*, 16. [\[CrossRef\]](#)
11. Hyde, K. An evaluation of the theoretical potential and practical opportunity for using recycled greywater for domestic purposes in Ghana. *J. Clean. Prod.* **2013**, *60*, 195–200. [\[CrossRef\]](#)
12. Khalkhali, M.; Dilkina, B.; Mo, W. The role of climate change and decentralization in urban water services: A dynamic energy-water nexus analysis. *Water Res.* **2021**, *207*, 117830. [\[CrossRef\]](#)
13. Proença, L.C.; Ghisi, E.; Tavares, D.D.; Coelho, G.M. Potential for electricity savings by reducing potable water consumption in a city scale. *Resour. Conserv. Recycl.* **2011**, *55*, 960–965. [\[CrossRef\]](#)
14. Cureau, R.J.; Ghisi, E. Electricity savings by reducing water consumption in a whole city: A case study in Joinville, Southern Brazil. *J. Clean. Prod.* **2020**, *261*, 121194. [\[CrossRef\]](#)
15. Kovalenko, Y.; Katkov, M.; Ponomarenko, I.; Malovanny, M.; Tymchuk, I. Utilization of drainage water heat in flooded urban areas. *Ecol. Questions* **2022**, *33*, 31–41. [\[CrossRef\]](#)
16. Neugebauer, G.; Lichtenwohrer, P.; Huber, F.; Stoeglehner, G.; Kretschmer, F. Potentials and Integrated Suitability Pre-assessment of Wastewater Treatment Plants as Local Energy Cells, *Front. Environ. Sci.* **2022**, *9*, 785557. [\[CrossRef\]](#)

17. Ravichandran, A.; Diaz-Elsayed, N.; Thomas, S.; Zhang, Q. An assessment of the influence of local conditions on the economic and environmental sustainability of drain water heat recovery systems. *J. Clean. Prod.* **2021**, *279*, 123589. [\[CrossRef\]](#)
18. Schestak, I.; Spriet, J.; Styles, D.; Williams, A.P. Introducing a Calculator for the Environmental and Financial Potential of Drain Water Heat Recovery in Commercial Kitchens. *Water* **2021**, *13*, 3486. [\[CrossRef\]](#)
19. Blechich, P.; Bonefacic, I.; Wolf, I. Space Heating and Cooling Energy Demand in Energy Efficient Single-Family House with Mechanical Ventilation System. *Tehnički vjesnik/Technical Gazette* **2017**, *24*, 119–126. [\[CrossRef\]](#)
20. Khaled, M.; Ali, S.; Jaber, H.; Faraj, J.; Murr, R.; Lemenand, T. Heating/Cooling Fresh Air Using Hot/Cold Exhaust Air of Heating, Ventilating, and Air Conditioning Systems. *Energies* **2022**, *15*, 1877. [\[CrossRef\]](#)
21. Kordana-Obuch, S.; Starzec, M. Horizontal Shower Heat Exchanger as an Effective Domestic Hot Water Heating Alternative. *Energies* **2022**, *15*, 4829. [\[CrossRef\]](#)
22. Khanlari, A.; Sözen, A.; Sahin, B.; Di Nicola, G.; Afshari, F. Experimental investigation on using building shower drain water as a heat source for heat pump systems. *Energ. Source Part A* **2020**, *44*, 1–13. [\[CrossRef\]](#)
23. Stec, A.; Mazur, A. An Analysis of Eco-Technology Allowing Water and Energy Saving in an Environmentally Friendly House—A Case Study from Poland. *Buildings* **2019**, *9*, 180. [\[CrossRef\]](#)
24. Shanableh, A.; Khalil, M.A.; Mustafa, A.; Abdallah, M.; Idris, A.E.; Yilmaz, A.; Merabtene, T.; Siddique, M.; Al-Ruzouq, R.; Imteaz, M.A.; et al. Greywater reuse experience in Sharjah, United Arab Emirates: Feasibility, challenges and opportunities. *Desalin. Water Treat.* **2020**, *179*, 211–222. [\[CrossRef\]](#)
25. Harnett, L.W.; Nicolson, J.D.; Tennant, R.J.; Dandy, G.C.; Maier, H.R. Sustainability trade-offs in the planning and design of cluster scale greywater reuse systems. In Proceedings of the 18th World IMACS Congress and MODSIM 2009—International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Cairns, Australia, 13–17 July 2009; pp. 3336–3342.
26. Wong, L.T.; Mui, K.W.; Guan, Y. Shower water heat recovery in high-rise residential buildings of Hong Kong. *Appl. Energ.* **2010**, *87*, 703–709. [\[CrossRef\]](#)
27. Neha, A.K. Acceptability of reclaimed municipal wastewater in cities: Evidence from India's National Capital Region. *Water Policy* **2022**, *24*, 212–228. [\[CrossRef\]](#)
28. Ifrim, V.C.; Milici, L.D.; Atănăsoae, P.; Irimia, D.; Pentiuc, R.D. Future Research Tendencies and Possibilities of Using Cogeneration Applications of Solar Air Heaters: A Bibliometric Analysis. *Energies* **2022**, *15*, 7114. [\[CrossRef\]](#)
29. Nagpal, H.; Spriet, J.; Murali, M.K.; McNabola, A. Heat Recovery from Wastewater—A Review of Available Resource. *Water* **2021**, *13*, 1274. [\[CrossRef\]](#)
30. El Hage, H.; Ramadan, M.; Jaber, H.; Khaled, M.; Olabi, A.G. A short review on the techniques of waste heat recovery from domestic applications. *Energ. Source. Part A* **2020**, *42*, 3019–3034. [\[CrossRef\]](#)
31. Pomianowski, M.Z.; Johra, H.; Marszał-Pomianowska, A.; Zhang, C. Sustainable and energy-efficient domestic hot water systems: A review. *Renew. Sust. Energ. Rev.* **2020**, *128*, 109900. [\[CrossRef\]](#)
32. Piotrowska, B.; Słyś, D.; Kordana-Obuch, S.; Pochwat, K. Critical Analysis of the Current State of Knowledge in the Field of Waste Heat Recovery in Sewage Systems. *Resources* **2020**, *9*, 72. [\[CrossRef\]](#)
33. Mazhar, A.R.; Liu, S.; Shukla, A. A Key Review of Non-Industrial Greywater Heat Harnessing. *Energies* **2018**, *11*, 386. [\[CrossRef\]](#)
34. Filali, H.; Barsan, N.; Souguir, D.; Nedeff, V.; Tomozei, C.; Hachicha, M. Greywater as an Alternative Solution for a Sustainable Management of Water Resources—A Review. *Sustainability* **2022**, *14*, 665. [\[CrossRef\]](#)
35. Elhegazy, H.; Eid, M.M.M. A state-of-the-art-review on grey water management: A survey from 2000 to 2020s. *Water Sci. Technol.* **2020**, *82*, 2786–2797. [\[CrossRef\]](#)
36. Roshan, A.; Kumar, M. Water end-use estimation can support the urban water crisis management: A critical review. *J. Environ. Manage.* **2020**, *268*, 110663. [\[CrossRef\]](#)
37. Vuppalladadiyam, A.K.; Merayo, N.; Prinsen, P.; Luque, R.; Blanco, A.; Zhao, M. A review on greywater reuse: Quality, risks, barriers and global scenarios. *Rev. Environ. Sci. Biotechnol.* **2019**, *18*, 77–99. [\[CrossRef\]](#)
38. Oteng-Peprah, M.; Acheampong, M.A.; deVries, N.K. Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—A Review. *Water Air Soil Pollut.* **2018**, *229*, 255. [\[CrossRef\]](#)
39. De Gisi, S.; Casella, P.; Notarnicola, M.; Farina, R. Grey water in buildings: A mini-review of guidelines, technologies and case studies. *Civ. Eng. Environ. Syst.* **2016**, *33*, 35–54. [\[CrossRef\]](#)
40. Pinto, U.; Maheshwari, B.L. Sustainable graywater reuse for residential landscape irrigation—A critical review. *Chinese J. Popul. Resour. Environ.* **2015**, *13*, 250–264. [\[CrossRef\]](#)
41. Li, Z.; Boyle, F.; Reynolds, A. Rainwater harvesting and greywater treatment systems for domestic application in Ireland. *Desalination* **2010**, *260*, 1–8. [\[CrossRef\]](#)
42. Maimon, A.; Tal, A.; Friedler, E.; Gross, A. Safe on-site reuse of greywater for irrigation—A critical review of current guidelines. *Environ. Sci. Technol.* **2010**, *44*, 3213–3220. [\[CrossRef\]](#)
43. Li, F.; Wichmann, K.; Otterpohl, R. Review of the technological approaches for grey water treatment and reuses. *Sci. Total Environ.* **2009**, *407*, 3439–3449. [\[CrossRef\]](#)
44. Exall, K. A Review of Water Reuse and Recycling, with Reference to Canadian Practice and Potential: 2. Applications. *Water Qual. Res. J. Canada* **2004**, *39*, 13–28. [\[CrossRef\]](#)

45. Brzozowska-Rup, K.; Nowakowska, M. Bibliometric Studies on Renewable Energy—Poland Compared to Other EU Countries. *Energies* **2022**, *15*, 4577. [\[CrossRef\]](#)
46. Sulich, A.; Sołoducho-Pelc, L. Changes in Energy Sector Strategies: A Literature Review. *Energies* **2022**, *15*, 7068. [\[CrossRef\]](#)
47. Fioramonte, B.; Campos, M.A.S.; de Freitas, S.R.; Basso, R.E. Rainfall data used for rainwater harvesting systems: A bibliometric and systematic literature review. *AQUA Water Infrastruct. Ecosyst. Soc.* **2022**, *71*, 816–834. [\[CrossRef\]](#)
48. Piadeh, F.; Behzadian, K.; Alani, A.M. A critical review of real-time modelling of flood forecasting in urban drainage systems. *J. Hydrol.* **2022**, *607*, 127476. [\[CrossRef\]](#)
49. Li, C.Z.; Li, S.; Li, X.; Wu, H.; Xiao, B.; Tam, V.W.Y.; Asiedu-Kwakyewa, C. A Scientometric Review of Management of Prefabricated Construction from 2011–2021. *Buildings* **2022**, *12*, 1515. [\[CrossRef\]](#)
50. Morante-Carballo, F.; Montalván-Burbano, N.; Quiñonez-Barzola, X.; Jaya-Montalvo, M.; Carrión-Mero, P. What Do We Know about Water Scarcity in Semi-Arid Zones? A Global Analysis and Research Trends. *Water* **2022**, *14*, 2685. [\[CrossRef\]](#)
51. van Eck, N.J.; Waltman, L. Visualizing Bibliometric Networks. In *Measuring Scholarly Impact: Methods and Practice*, 1st ed.; Ding, Y., Rousseau, R., Wolfram, D., Eds.; Springer: Cham, Switzerland, 2014; pp. 285–320. [\[CrossRef\]](#)
52. van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [\[CrossRef\]](#)
53. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [\[CrossRef\]](#)
54. Lagos, A.; Caicedo, J.E.; Coria, G.; Quete, A.R.; Martínez, M.; Suvire, G.; Riquelme, J. State-of-the-Art Using Bibliometric Analysis of Wind-Speed and -Power Forecasting Methods Applied in Power Systems. *Energies* **2022**, *15*, 6545. [\[CrossRef\]](#)
55. Wong, C.S. Science Mapping: A Scientometric Review on Resource Curses, Dutch Diseases, and Conflict Resources during 1993–2020. *Energies* **2021**, *14*, 4573. [\[CrossRef\]](#)
56. Bajdor, P.; Starostka-Patyk, M. Smart City: A Bibliometric Analysis of Conceptual Dimensions and Areas. *Energies* **2021**, *14*, 4288. [\[CrossRef\]](#)
57. Waltman, L.; van Eck, N.J.; Noyons, E.C.M. A unified approach to mapping and clustering of bibliometric networks. *J. Informetr.* **2010**, *4*, 629–635. [\[CrossRef\]](#)
58. Amanowicz, Ł. Peak Power of Heat Source for Domestic Hot Water Preparation (DHW) for Residential Estate in Poland as a Representative Case Study for the Climate of Central Europe. *Energies* **2021**, *14*, 8047. [\[CrossRef\]](#)
59. Rzeźnik, W.; Rzeźnik, I.; Hara, P. Comparison of Real and Forecasted Domestic Hot Water Consumption and Demand for Heat Power in Multifamily Buildings, in Poland. *Energies* **2022**, *15*, 6871. [\[CrossRef\]](#)
60. Ruszel, M.; Masłoń, A.; Ogarek, P. Analysis of biogas from sewage sludge digestion in terms of diversification in the natural gas production structure in Poland. *Desalin. Water Treat.* **2021**, *232*, 298–307. [\[CrossRef\]](#)
61. Østergaard, D.S.; Smith, K.M.; Tunzi, M.; Svendsen, S. Low-temperature operation of heating systems to enable 4th generation district heating: A review. *Energy* **2022**, *248*, 123529. [\[CrossRef\]](#)
62. Wehbi, Z.; Taher, R.; Faraj, J.; Ramadan, M.; Castelain, C.; Khaled, M. A short review of recent studies on wastewater heat recovery systems: Types and applications. *Energy Reports* **2022**, *8*, 896–907. [\[CrossRef\]](#)
63. López González, L.M.; Míguez Tabarés, J.L.; Gándara Alvarez, M.; Viar, P.F. Feasibility study for the installation of HVAC for a spa by means of energy recovery from thermal water—Part I: Analysis of conditions. *Renew. Energ.* **2001**, *23*, 123–134. [\[CrossRef\]](#)
64. Míguez Tabarés, J.L.; Gándara Alvarez, M.; López González, L.M.; Viar, P.F. Feasibility study for the installation of HVAC for a spa by means of energy recovery from thermal water—Part II: Energy analysis. *Renew. Energ.* **2001**, *23*, 135–149. [\[CrossRef\]](#)
65. Gill, G.S.; Fung, A.S. 30-Year life cycle cost of solar based domestic hot water systems for Ontario. In Proceedings of the 2nd International Conference on Energy Sustainability, ES 2008, Jacksonville, FL, USA, 10–14 August 2008.
66. Leidl, C.M.; Lubitz, W.D. Comparing domestic water heating technologies. *Technol. Soc.* **2009**, *31*, 244–256. [\[CrossRef\]](#)
67. Bartkowiak, S.; Fisk, R.; Funk, A.; Hair, J.; Skerlos, S.J. Residential drain water heat recovery systems: Modeling, analysis, and implementation. *J. Green Build.* **2010**, *5*, 85094. [\[CrossRef\]](#)
68. Guo, Y.X.; Cai, Y.L.; Liang, S.Q.; Chen, W. Experimental study on a shower waste water heat recovery device in buildings. *Appl. Mech. Mater.* **2012**, *226–228*, 2402–2406. [\[CrossRef\]](#)
69. Hadengue, B.; Morgenroth, E.; Larsen, T.A. Screening innovative technologies for energy-efficient domestic hot water systems. *J. Environ. Manage.* **2022**, *320*, 115713. [\[CrossRef\]](#) [\[PubMed\]](#)
70. Collins, M.R.; Van Decker, G.W.E.; Murray, J. Characteristic effectiveness curves for falling-film drain water heat recovery systems. *HVAC R Res.* **2013**, *19*, 649–662. [\[CrossRef\]](#)
71. Liu, X.; Ni, L.; Lau, S.K.; Li, H. Performance analysis of a multi-functional Heat pump system in heating mode. *Appl. Therm. Eng.* **2013**, *51*, 698–710. [\[CrossRef\]](#)
72. Li, X.; Gul, M.; Sharmin, T.; Nikolaidis, I.; Al-Hussein, M. A framework to monitor the integrated multi-source space heating systems to improve the design of the control system. *Energ. Buildings* **2014**, *72*, 398–410. [\[CrossRef\]](#)
73. Morales-Ruiz, S.; Rigola, J.; Oliet, C.; Oliva, A. Analysis and design of a drain water heat recovery storage unit based on PCM plates. *Appl. Energ.* **2016**, *179*, 1006–1019. [\[CrossRef\]](#)
74. Torras, S.; Oliet, C.; Rigola, J.; Oliva, A. Drain water heat recovery storage-type unit for residential housing. *Appl. Therm. Eng.* **2016**, *103*, 670–683. [\[CrossRef\]](#)

75. Gabor, T.; Dan, V.; Badila, I.N.; Tiuc, A.E.; Sur, I.M. Improving the energy efficiency of residential buildings by using a drain water heat recovery system. *Environ. Eng. Manag. J.* **2017**, *16*, 1631–1636. [\[CrossRef\]](#)
76. Wallin, J.; Claesson, J. Analyzing the efficiency of a heat pump assisted drain water heat recovery system that uses a vertical inline heat exchanger. *Sustain. Energy Technol. Assess.* **2014**, *8*, 109–119. [\[CrossRef\]](#)
77. Tanha, K.; Fung, A.S.; Kumar, R. Simulation and experimental investigation of two hybrid solar domestic water heaters with drain water heat recovery. *Int. J. Energ. Res.* **2015**, *39*, 1879–1889. [\[CrossRef\]](#)
78. Ramadan, M.; Murr, R.; Khaled, M.; Olabi, A.G. Mixed numerical—Experimental approach to enhance the heat pump performance by drain water heat recovery. *Energy* **2018**, *149*, 1010–1021. [\[CrossRef\]](#)
79. Manouchehri, R.; Collins, M.R. Modelling the steady-state performance of coiled falling-film drain water heat recovery systems using rated data. *Resources* **2020**, *9*, 69. [\[CrossRef\]](#)
80. Yuan, X.; Lindroos, L.; Jokisalo, J.; Kosonen, R. Study on waste heat recoveries and energy saving in combined energy system of ice and swimming halls in Finland. *Energ. Buildings* **2021**, *231*, 110620. [\[CrossRef\]](#)
81. Hervás-Blasco, E.; Navarro-Peris, E.; Corberán, J.M. Closing the residential energy loop: Grey-water heat recovery system for domestic hot water production based on heat pumps. *Energ. Buildings* **2020**, *216*, 109962. [\[CrossRef\]](#)
82. Mazhar, A.R.; Zou, Y.; Liu, S.; Shen, Y.; Shukla, A. Development of a PCM-HE to harness waste greywater heat: A case study of a residential building. *Appl. Energ.* **2022**, *307*, 118164. [\[CrossRef\]](#)
83. Hadengue, B.; Morgenroth, E.; Larsen, T.A.; Baldini, L. Performance and dynamics of active greywater heat recovery in buildings. *Appl. Energ.* **2022**, *305*, 117677. [\[CrossRef\]](#)
84. Vavříčka, R.; Boháč, J.; Matuška, T. Experimental development of the plate shower heat exchanger to reduce the domestic hot water energy demand. *Energ. Buildings* **2022**, *254*, 111536. [\[CrossRef\]](#)
85. Manouchehri, R.; Collins, M.R. Investigating the Impact of Plumbing Configuration on Energy Savings for Falling-Film Drain Water Heat Recovery Systems. *Energies* **2022**, *15*, 1141. [\[CrossRef\]](#)
86. Sayegh, M.A.; Ludwińska, A.; Rajski, K.; Dudkiewicz, E. Environmental and energy saving potential from greywater in hotels. *Sci. Total Environ.* **2021**, *761*, 143220. [\[CrossRef\]](#) [\[PubMed\]](#)
87. Kordana-Obuch, S.; Starzec, M.; Słyś, D. Assessment of the Feasibility of Implementing Shower Heat Exchangers in Residential Buildings Based on Users' Energy Saving Preferences. *Energies* **2021**, *14*, 5547. [\[CrossRef\]](#)
88. Selimli, S.; Abajja, K.M.A. Recovery of greywater thermal energy with a wire on a tube heat exchanger attached to a dishwasher. *Water Environ. Res.* **2021**, *93*, 1333–1345. [\[CrossRef\]](#) [\[PubMed\]](#)
89. Selimli, S.; Eljetlawi, I.A.M. The experimental study of thermal energy recovery from shower greywater. *Energ. Source. Part A* **2021**, *43*, 3032–3044. [\[CrossRef\]](#)
90. Liebersbach, J.; Żabnieńska-Góra, A.; Polarczyk, I.; Sayegh, M.A. Feasibility of Grey Water Heat Recovery in Indoor Swimming Pools. *Energies* **2021**, *14*, 4221. [\[CrossRef\]](#)
91. Salama, M.; Sharqawy, M.H. Experimental investigation of the performance of a falling-film drain water heat recovery system. *Appl. Therm. Eng.* **2020**, *179*, 115712. [\[CrossRef\]](#)
92. Murr, R.; Khaled, M.; Faraj, J.; Harika, E.; Abdulhay, B. Multi drain heat recovery system—Thermal modeling, parametric analysis, and case study. *Energ. Buildings* **2020**, *228*, 110447. [\[CrossRef\]](#)
93. Kordana, S.; Pochwat, K.; Słyś, D.; Starzec, M. Opportunities and Threats of Implementing Drain Water Heat Recovery Units in Poland. *Resources* **2019**, *8*, 88. [\[CrossRef\]](#)
94. Spriet, J.; McNabola, A. Decentralized drain water heat recovery from commercial kitchens in the hospitality sector. *Energ. Buildings* **2019**, *194*, 247–259. [\[CrossRef\]](#)
95. Spriet, J.; McNabola, A. Decentralized drain water heat recovery: A probabilistic method for prediction of wastewater and heating system interaction. *Energ. Buildings* **2019**, *183*, 684–696. [\[CrossRef\]](#)
96. Ip, K.; She, K.; Adeyeye, K. Life-cycle impacts of shower water waste heat recovery: Case study of an installation at a university sport facility in the UK. *Environ. Sci. Pollut. R.* **2018**, *25*, 19247–19258. [\[CrossRef\]](#)
97. Akbarzadeh, P.; Nejad, A.A.; Movahed, F.; Zolfaghari, S. A New Approach to Numerical Investigation of GFX And Power-Pipe Drain Water Heat Recovery (DWHR) Systems in Buildings. *Heat Transf. Res.* **2018**, *49*, 1339–1352. [\[CrossRef\]](#)
98. Zhang, J.; Yu, Q.; Zheng, F.; Long, C.; Lu, Z.; Duan, Z. Comparing keywords plus of WOS and author keywords: A case study of patient adherence research. *J. Assoc. Inf. Sci. Technol.* **2015**, *67*, 967–972. [\[CrossRef\]](#)
99. Frijns, J.; Hofman, J.; Nederlof, M. The potential of (waste)water as energy carrier. *Energ. Convers. Manag.* **2013**, *65*, 357–363. [\[CrossRef\]](#)
100. Liu, L.; Fu, L.; Jiang, Y. Application of an exhaust heat recovery system for domestic hot water. *Energy* **2010**, *35*, 1476–1481. [\[CrossRef\]](#)
101. McNabola, A.; Shields, K. Efficient drain water heat recovery in horizontal domestic shower drains. *Energ. Buildings* **2013**, *59*, 44–49. [\[CrossRef\]](#)
102. Bertrand, A.; Aggoune, R.; Maréchal, F. In-building waste water heat recovery: An urban-scale method for the characterisation of water streams and the assessment of energy savings and costs. *Appl. Energ.* **2017**, *192*, 110–125. [\[CrossRef\]](#)
103. Ritchie, H.; Roser, M. Water Use and Stress. 2017. Available online: [Ourworldindata.org/water-use-stress](https://ourworldindata.org/water-use-stress) (accessed on 14 November 2022).

104. Kepa, U.; Stepniak, L.; Stanczyk-Mazanek, E.; Chudzik, K. Analysis of the Structure of Water Demand with the Example of Selected Buildings. *Water* **2019**, *11*, 1635. [\[CrossRef\]](#)
105. Rathnayaka, K.; Malano, H.; Arora, M.; George, B.; Maheepala, S.; Nawarathna, B. Prediction of urban residential end-use water demands by integrating known and unknown water demand drivers at multiple scales I: Model development. *Resour. Conserv. Recycl.* **2017**, *117*, 85–92. [\[CrossRef\]](#)
106. Batisha, A.F. Greywater in Egypt: The sustainable future of non-conventional water resources. *Environ. Sci. Pollut. Res.* **2020**, *27*, 35428–35438. [\[CrossRef\]](#)
107. Al-Jayyousi, O. Focused environmental assessment of greywater reuse in Jordan. *Environ. Eng. Policy* **2001**, *3*, 67–73. [\[CrossRef\]](#)
108. Rodríguez, C.; Sánchez, R.; Lozano-Parra, J.; Rebolledo, N.; Schneider, N.; Serrano, J.; Leiva, E. Water Balance Assessment in Schools and Households of Rural Areas of Coquimbo Region, North-Central Chile: Potential for Greywater Reuse. *Water* **2020**, *12*, 2915. [\[CrossRef\]](#)
109. Beler-Baykal, B. Stream Segregation in Household Use: A Review of Grey Water as an Alternative Source of Water and Yellow Water as an Alternative Source of Fertilizers. *Water Qual. Expo. Health* **2015**, *7*, 27–37. [\[CrossRef\]](#)
110. Cureau, R.J.; Ghisi, E. Reduction of Potable Water Consumption and Sewage Generation on a City Scale: A Case Study in Brazil. *Water* **2019**, *11*, 2351. [\[CrossRef\]](#)
111. Safarpour, H.; Tabesh, M.; Shahangian, S.A.; Hajibabaei, M.; Sitzenfrei, R. Life Cycle Sustainability Assessment of Wastewater Systems under Applying Water Demand Management Policies. *Sustainability* **2022**, *14*, 7736. [\[CrossRef\]](#)
112. Ho, G.; Dallas, S.; Anda, M.; Mathew, K. On-site wastewater technologies in Australia. *Water Sci. Technol.* **2001**, *44*, 81–88. [\[CrossRef\]](#)
113. Diaper, C.; Jefferson, B.; Parsons, S.A.; Judd, S.J. Water-Recycling Technologies in the UK. *Water Environ. J.* **2001**, *15*, 282–286. [\[CrossRef\]](#)
114. Faruqui, N.; Al-Jayyousi, O. Greywater Reuse in Urban Agriculture for Poverty Alleviation—A Case Study in Jordan. *Water Int.* **2002**, *27*, 387–394. [\[CrossRef\]](#)
115. Nolde, E. Greywater recycling systems in Germany—Results, experiences and guidelines. *Water Sci. Technol.* **2005**, *51*, 203–210. [\[CrossRef\]](#)
116. Friedler, E.; Hadari, M. Economic feasibility of on-site greywater reuse in multi-storey buildings. *Desalination* **2006**, *190*, 221–234. [\[CrossRef\]](#)
117. Ghisi, E.; Ferreira, D.F. Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil. *Build. Environ.* **2007**, *42*, 2512–2522. [\[CrossRef\]](#)
118. Ghisi, E.; de Oliveira, S.M. Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. *Build. Environ.* **2007**, *42*, 1731–1742. [\[CrossRef\]](#)
119. Brown, R.R.; Davies, P. Understanding community receptivity to water re-use: Ku-ring-gai Council case study. *Water Sci. Technol.* **2007**, *55*, 283–290. [\[CrossRef\]](#)
120. Marinovski, A.K.; Ghisi, E. Environmental performance of hybrid rainwater-greywater systems in residential buildings. *Resour. Conserv. Recycl.* **2019**, *144*, 100–114. [\[CrossRef\]](#)
121. Rodríguez, C.; Sánchez, R.; Rebolledo, N.; Schneider, N.; Serrano, J.; Leiva, E. Cost–Benefit Evaluation of Decentralized Greywater Reuse Systems in Rural Public Schools in Chile. *Water* **2020**, *12*, 3468. [\[CrossRef\]](#)
122. Suchorab, P.; Iwanek, M.; Żelazna, A. Profitability analysis of dual installations in selected European countries. *Appl. Water Sci.* **2021**, *11*, 34. [\[CrossRef\]](#)
123. Al-Jayyousi, O.R. Greywater reuse: Towards sustainable water management. *Desalination* **2003**, *156*, 181–192. [\[CrossRef\]](#)
124. Domènech, L.; Sauri, D. Socio-technical transitions in water scarcity contexts: Public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resour. Conserv. Recycl.* **2010**, *55*, 53–62. [\[CrossRef\]](#)
125. Gómez-Monsalve, M.; Domínguez, I.C.; Yan, X.; Ward, S.; Oviedo-Ocaña, E.R. Environmental performance of a hybrid rainwater harvesting and greywater reuse system: A case study on a high water consumption household in Colombia. *J. Clean. Prod.* **2022**, *345*, 131125. [\[CrossRef\]](#)
126. Portman, M.E.; Vdov, O.; Schuetze, M.; Gilboa, Y.; Friedler, E. Public perceptions and perspectives on alternative sources of water for reuse generated at the household level. *Water Reuse* **2022**, *12*, 157–174. [\[CrossRef\]](#)
127. Amaris, G.; Hess, S.; Gironás, J.; Ortúzar, J.D. Using hybrid choice models to capture the impact of attitudes on residential greywater reuse preferences. *Resour. Conserv. Recycl.* **2021**, *164*, 105171. [\[CrossRef\]](#)
128. Arden, S.; Morelli, B.; Cashman, S.; Ma, X.; Jahne, M.; Garland, J. Onsite Non-potable Reuse for Large Buildings: Environmental and Economic Suitability as a Function of Building Characteristics and Location. *Water Res.* **2021**, *191*, 116635. [\[CrossRef\]](#)
129. Radingoana, M.P.; Dube, T.; Mazvimavi, D. Progress in greywater reuse for home gardening: Opportunities, perceptions and challenges. *Phys. Chem. Earth Parts A/B/C* **2020**, *116*, 102853. [\[CrossRef\]](#)
130. Byrne, J.; Dallas, S.; Anda, M.; Ho, G. Quantifying the Benefits of Residential Greywater Reuse. *Water* **2020**, *12*, 2310. [\[CrossRef\]](#)
131. da Silva, L.C.C.; Filho, D.O.; Silva, I.R.; Pinto, A.C.V.; Vaz, P.N. Water sustainability potential in a university building—Case study. *Sustain. Cities Soc.* **2019**, *47*, 101489. [\[CrossRef\]](#)
132. Zhu, J.; Wagner, M.; Cornel, P.; Chen, H.; Dai, X. Feasibility of on-site grey-water reuse for toilet flushing in China. *J. Water Reuse Desalin.* **2018**, *8*, 1–13. [\[CrossRef\]](#)

133. Wanjiru, E.; Xia, X. Sustainable energy-water management for residential houses with optimal integrated grey and rain water recycling. *J. Clean. Prod.* **2018**, *170*, 1151–1166. [[CrossRef](#)]
134. Shafiquzzaman, M.; Haider, H.; AlSaleem, S.S.; Ghumman, A.R.; Sadiq, R. Development of Consumer Perception Index for assessing greywater reuse potential in arid environments. *Water SA* **2018**, *44*, 771–781. [[CrossRef](#)]
135. Taemthong, W. Grey water recycling for reuse in toilet flushing: A case study in Thailand. *J. Green Build.* **2018**, *13*, 73–82. [[CrossRef](#)]
136. Li, Y.; Khalkhali, M.; Mo, W.; Lu, Z. Modeling spatial diffusion of decentralized water technologies and impacts on the urban water systems. *J. Clean. Prod.* **2021**, *315*, 128169. [[CrossRef](#)]
137. Naserisafavi, N.; Yaghoubi, E.; Sharma, A.K. Alternative water supply systems to achieve the net zero water use goal in high-density mixed-use buildings. *Sustain. Cities Soc.* **2022**, *76*, 103414. [[CrossRef](#)]
138. Mota, F.S. Proposals for water conservation in urban areas in Brazil. *Desenvolv. Meio Ambiente* **2022**, *59*, 134–157. [[CrossRef](#)]
139. Stec, A.; Mazur, A.; Słyś, D. Evaluating the financial efficiency of energy and water saving installations in passive house. *E3S Web Conf.* **2017**, *22*, 00168. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.