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Article

Energy Consumption in Higher Education Institutions. A Computational Bibliometric Analysis Focused on Scientific Trends and Common Drivers

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Abstract: Universities must be paragons of virtue on sustainability, as they hold a flagship position in society. Nevertheless, Higher Education Institutions (HEIs) are intensive energy consumers. This paper analyzes academic trends and common drivers of energy consumption in HEIs, through a Systematic Literature Review aided by computer-based routines. While this subject has been researched under a combination of technical disciplines, the involvement of social sciences is limited. The USA, China and the UK are the leading countries in terms of scholarly output about Universities' energy consumption. The University of Sheffield leads in terms of publishing papers about this subject, while Energy and Buildings is the most utilized journal. Zhonghua Gou is the most productive author researching this matter, while Mehreen Gul and Sandhya Patidar are the most cited. Factors driving energy consumption in Universities are common to different geographical areas, and generally do not differ from those of other sectors, although Building Function, Research Intensity and Discipline orientation are shown to be specific to HEIs. A more prominent involvement of the social sciences in academic research on this matter is recommended. Depending on whether HEIs are teaching or research oriented, different building designs strategies should be considered, to reduce energy consumption.

Keywords: academic trends; energy consumption; higher education institutions; systematic literature review; scholarly output; university buildings

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1. Introduction

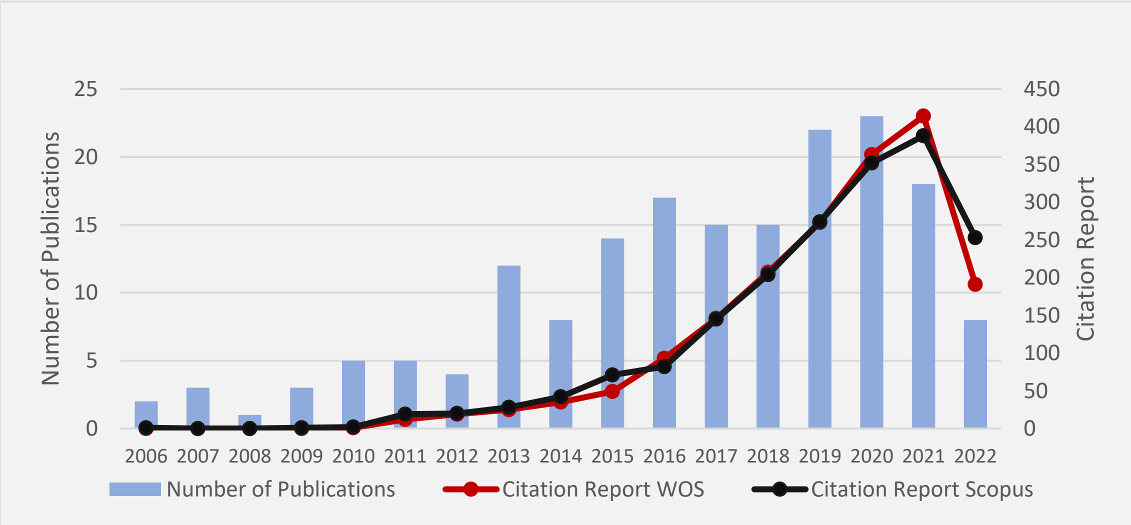
Universities must set an example of sustainable management, striving to achieve a positive impact on society. Higher education leaders hold important responsibilities in terms of balancing financial, social, and environmental objectives, which are often intertwined. They should understand that Universities´ goals (educating students, generating and distributing knowledge) demand a large amount of resources; therefore, the different types of Higher Education Institutions (HEIs) must seek to reduce energy consumption (EC) and cut costs [1].

University buildings are intensive energy and water consumers, with specific consumption factors and patterns that have been less studied than other types of buildings [2]. Each University has specific EC characteristics, depending on the institution's orientation and its area of specialization [3]. Premises in HEIs are often described as energy intensive [4], with electricity being their major source of energy, used in heating and cooling systems, laboratories, lighting systems, elevators, as well as computing and instructional facilities [5].

The higher education sector impacts the environment. Many Universities have realized the extent of this impact and have taken measures to reduce it. They do so through initiatives such as raising awareness about unnecessary energy use, developing more energy efficient facilities and implementing renewable energy generation projects on campus [6]. Consequently, Universities have been working to lessen both their greenhouse gas (GHG) emissions and their EC, prioritizing renewable and sustainable energy sources [7,8].

Universities, both public and private, play an important role in society. They face the challenge of educating future graduates on a sustainable culture [9], fostering more responsible and environmentally conscious professional behavior. Also, HEIs have to be role models by engaging in specific actions that demonstrate their commitment to sustainable principles [10]. Furthermore, Universities lead the research activities seeking technological progress towards a post-carbon civilization [11], playing a flagship role in the endeavors to understand and mitigate climate change.

Our study focuses on EC in Universities, which has become an emerging field of research. Several researchers have studied EC patterns among specific Universities in countries such Ecuador, Greece, Mexico, the USA and Turkey (see examples in Appendix A). As shown in Graph 1, there is increasing academic interest in the EC of HEIs. This is reflected in the constant growth in both the number of articles published and in the amount of citations; moreover, both figures have reached their highest values in recent years. We believe that this sustained surge in academic interest on this topic justifies carrying out a Systematic Literature Review (SLR) on this area.



Source: Own elaboration from Web of Science Core Collection / Scopus Database

Extracted on 4-27-22

Graph 1. Selected publications and citations about EC in Universities.

A review of selected literature about models of sustainable practices in Universities, unrestricted in its geographical scope, was carried by Mohammadalizadehkorde and Weaver [12]. They reviewed the bibliography on the sustainability of Universities, synthesizing large groups of literature, but describing their study as "necessarily non-exhaustive". Therefore, we believe that the aims and methodology of their research differs from ours.

Although there have been academic studies focusing specifically on certain Universities or geographical areas, to the best of our knowledge there are no scientific articles which address EC in Universities by analyzing the factors that are common to HEIs in different regions or countries. Overall, research about EC in the higher education sector is still in its early stages [13,14]. Moreover, the issue of consumption patterns in HEI buildings remains somewhat overlooked [15]. Consequently, there is a knowledge gap about common characteristics of EC within the higher education sector at an international scale, which is worth investigating. Filling the aforementioned knowledge gap will help Universities to fulfil their role as leaders in society; indeed, doing so is the main motivation for this research.

Additionally, we have identified a lack of understanding about the academic trends forging this topic. The simple review of the scientific sources points to some authors, countries and HEIs as forerunners in scholarly output; nevertheless, a more thorough analysis must be undertaken to determine how knowledge has been spread. Also, as mentioned above, reducing Universities' EC encompasses both technical and managerial aspects. Consequently, it is important to clarify whether the research on this topic has been oriented towards exact sciences or social sciences. This can be determined by analyzing the discipline orientation of journals and conference proceedings used to disseminate the scientific articles. Previous studies have used the Herfindahl–Hirschman index as a measure of multidisciplinarity [16] on a given topic. This index is an important tool used by regulators to evaluate market concentration [17] and we propose that it can be applied to measure the level of concentration of different aspects of a bibliometric analysis.

Considering these knowledge gaps, the aim of this article is threefold: 1) to determine the key characteristic of scientific papers about EC in Universities; 2) to analyze the current academic trends in the topic, identifying leading authors, countries and Universities; 3) to explore the main factors explaining EC in Universities. The analysis was carried out for the period 2006 to 2022. This 16-year time span was selected to cover the period in which there has been a considerable surge in the publications about the studied topic (see Graph 1).

The major findings are that: i) this topic has been studied under a combination of technical disciplines, but there has been only limited involvement of social sciences; ii) the USA, China and the UK are the leading countries in scholarly output about EC in HEIs; iii) the University of Sheffield leads in terms of publishing papers about this subject, while Energy and Buildings is the most utilized journal; Zhonghua Gou is the most productive author researching this topic, whereas Gul and Patidar are the most cited ones; and iv) factors driving EC in Universities do not differ from those of other sectors.

The rest of the paper is structured as follows. Section 2 explains the methodological approach of the SLR. Section 3 presents the results. Sector 4 offers a discussion of the results, while the main conclusions are drawn in section 5.

2. Methodology

The three objectives of this article will be addressed through an SLR. This is a method that aims to enhance the level of the review process. It uses a structured, organized, and reproducible approach to extract evidence about a certain issue or topic from reliable research [18]. An SLR entails identifying and selecting primary studies; then, data have to be extracted, analyzed, and synthesized [19].

This article utilizes a procedure adapted from the APPISER methodology [20] which comprises six phases: A Priori (selecting the knowledge gap and proposing the research questions), Plan, Identify, Screen and Select, Extract, and Report.

2.1. Research Questions

Since Universities are the main driving force of academic research, it is important to understand how the scientific community has investigated the topic in question. Therefore, this article specifically addresses EC in HEIs, using an SLR to answer the following research questions:

1) Regarding the sources publishing academic articles about EC in Universities, what are their main characteristics? Answering this question will allow us to identify leading journals, the degree of concentration among sources, and level of multidisciplinarity involved.
2) In terms of scholarly output on this topic, which countries, Universities, and authors are the most prolific producers of scientific publications?
3) According to the literature, what are the factors determining the EC in Universities?

2.2. Plan

This article searches for and analyzes scientific publications in the Web of Science (WOS) Core Collection, SciELO and Scopus Database through a combination of keywords related to HEIs and energy.

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2.3. Identify

In order to select the most pertinent set of publications about EC in Universities and to restrict the outcome to a manageable number of articles, a computer-based routine relying on Visual Basic and Microsoft Access was developed. The size and composition of the target set of publications was established at 900-950 publications with at least 25% of WOS articles. In each iteration of the method, the metadata of selected publications were extracted, reorganized, and entered into a database. Iteratively, several queries with different keywords were run on the aforementioned databases. Each query was a combination of two clauses joined by an "OR" operator. The first clause denoted the object to be investigated (e.g., "Higher Education", "University Buildings", etc.). The second clause addressed the dependent variables to be analyzed (e.g., "Energy", "Energy Consumption" etc.), with keywords being changed in each iteration; this was done in order to obtain articles that could potentially answer the research questions, while trying to reach the targeted amount and composition of the final set of papers. The outcome of each iteration was analyzed in terms of the number of articles containing each keyword. On the basis of this information, the keywords to be used in the next iteration were selected. The search keywords used in each query are presented in Table 1. The result of each query in terms of the number of articles found is presented in Table 2.

Table 1. Keywords used in each query.

KEYWORD	TYPE	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S_Final
CAMPUS	Object	NO	NO	NO	NO	NO	YES	YES	NO	NO	YES	WOS/SCIELO
EDUCATIONAL INSTITUTIONS	Object	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
HIGHER EDUCATION	Object	NO	YES	YES	NO	NO	YES	YES	YES	YES	YES	YES
HIGHER EDUCATION BUILDINGS	Object	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
HIGHER EDUCATION INSTITUTION	Object	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
HIGHER EDUCATION INSTITUTIONS	Object	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
UNIVERSITIES	Object	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO
UNIVERSITIES*	Object	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
UNIVERSITY	Object	YES	YES	YES	NO	NO	NO	NO	NO	NO	YES	WOS/SCIELO
UNIVERSITY BUILDING	Object	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
UNIVERSITY BUILDINGS	Object	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
UNIVERSITY CAMPUS	Object	NO	NO	NO	YES	NO	YES	YES	YES	YES	YES	YES
UNIVERSITY CAMPUS*	Object	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO
UNIVERSITY CAMPUSES	Object	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	WOS/SCIELO
UNIVERSITY OPERATIONS	Object	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	WOS/SCIELO
UNIVERSITY SECTOR	Object	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
ELECTRICAL ENERGY CONSUMPTION	Dependent	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
ELECTRICITY CONSUMPTION	Dependent	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
ELECTRICITY-CONSUMPTION	Dependent	NO	NO	NO	NO	NO	NO	YES	NO	YES	NO	SCOPUS

ENERGY	Dependent	NO	NO	YES	YES	YES	YES	NO	NO	NO	YES	WOS/SCIELO
ENERGY CONSERVATION	Dependent	NO	NO	NO	NO	NO	NO	YES	YES	YES	NO	SCOPUS
ENERGY CONSUMPTION	Dependent	NO	YES	NO	NO	NO	NO	YES	YES	YES	NO	SCOPUS
ENERGY EFFICIENCY	Dependent	YES	YES	NO	NO	NO	NO	YES	YES	YES	NO	SCOPUS
ENERGY EXPENDITURE	Dependent	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
ENERGY INTAKE	Dependent	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
ENERGY Intensity	Dependent	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
ENERGY SAVING	Dependent	NO	YES	NO	NO	NO	NO	YES	NO	NO	NO	NO
ENERGY SAVINGS	Dependent	YES	YES	NO	NO	NO	NO	NO	NO	YES	NO	SCOPUS
ENERGY USE	Dependent	NO	NO	NO	NO	NO	NO	YES	YES	YES	NO	SCOPUS
ENERGY USE INTENSITY	Dependent	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO
ENERGY UTILIZATION	Dependent	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO

Source: Own elaboration. (*) A special operator was used in SCOPUS restricting search to the plural form of the keyword. Yes : Included. No: Not included. WOS/SCIELO: Only used in WOS and SCIELO Databases. SCOPUS: Only used in SCOPUS Database.

Table 2. Outcome of the queries.

SOURCE	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S_FINAL
SCIELO	2	3	14	1	3	1				14	15
SCIELO/SCOPUS			1			2	1			1	
SCOPUS	1,127	1,777	8,515	8,276	1,690	2,376	1,212	581	607	8,754	577
WOS	5	7	55	11	11	33	9	5	7	70	257
WOS/SCOPUS	29	62	209	41	41	181	90	47	53	271	84
Total general	**1,163**	**1,849**	**8,794**	**8,329**	**1,745**	**2,593**	**1,312**	**633**	**667**	**9,110**	**933**

Source: Own elaboration.

As presented in Table 2, the number of documents encountered in queries on the Scopus database heavily outweighs the number found in WOS and SciELO. Publications found simultaneously in the WOS and Scopus databases were denominated "WOS/SCOPUS", and those found in SciELO and Scopus denoted by "SCIELO/SCOPUS". The final query, which delivered the set of papers to be analyzed, was a combination of queries S09 for SCOPUS and S10 for WOS +SCIELO; it is shown as S_Final[1] in Table 1. As can be seen in Table 2 , query S_Final delivered 15 SCIELO, 577 SCOPUS, 257 WOS and 84 WOS/SCOPUS publications.

There were 84 publications shared by the WOS and Scopus databases (see Table 2). Nevertheless, since the search strings are not the same (see * in Table 1) and Scopus and WOS use different internal keywords criteria, 50 publications that are contained in both databases (not included in the 84 "shared" publications) do not appear (in this stage) to be duplicated in the outcome. These coinciding appearances were manually re-classified as WOS/SCOPUS after the final screening.

[1] *Extracted on April 27, 2022*

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2.4. Screen and Select

Having preselected 933 publications, a scan was conducted on their title and abstract to select a set of articles that address the research questions. This was done considering a set of three conditions:

C1) EC in buildings

This condition evaluates whether the title and the abstract of the document selected suggest that it analyzes some or several factors that explain EC in any kind of building. C1 focused on EC, leaving out, for example, papers which tackle energy generation initiatives or the energy sources suppling HEIs.

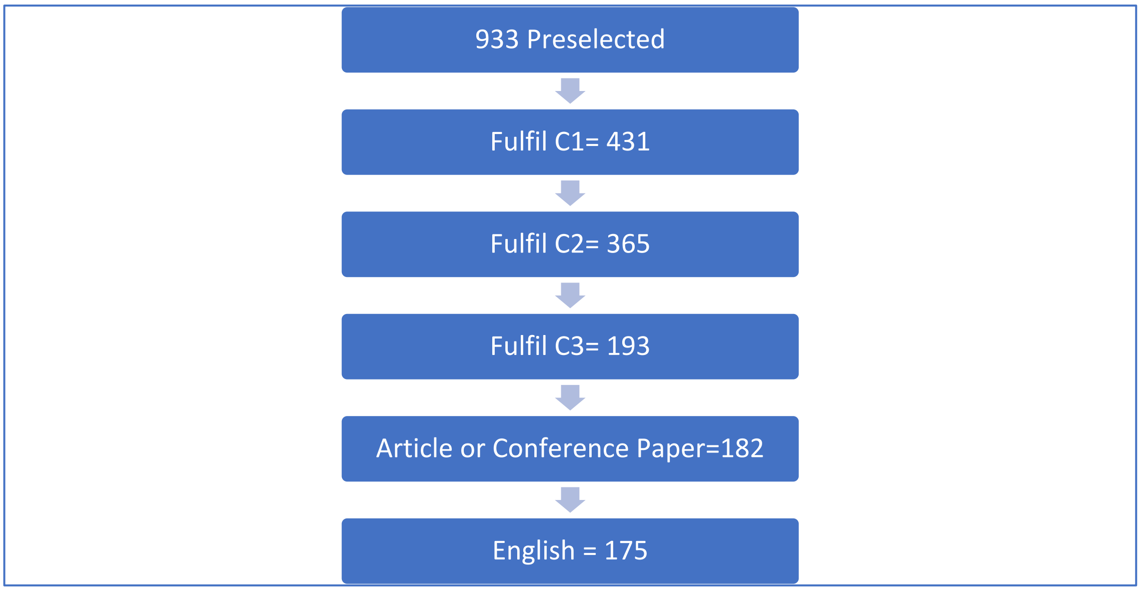
C2) EC in Universities

If C1 is satisfied, then only articles studying University buildings are selected, discarding papers about other kind of edifices.

C3) Factors explaining EC in Universities:

C3 evaluates whether the title and the abstract of the document suggest that it focuses on analyzing EC in Universities and its determinants. The article under analysis must focus on EC in HEIs; therefore, papers that deal with this topic but not as their primary objective were omitted from the selection. Also, articles studying energy generation plants managed by Universities, energy distribution and energy management systems such as micro grids or smart grids were left out.

Figure 1 shows 193 publications fulfilling the three conditions for inclusion. Additionally, only texts catalogued as "articles" or "conference papers" in the databases and written in English were selected. The application of these conditions yielded a final set of 175 publications (see Appendix B). The final selection of papers is shown in Table 3.



Source: Own Elaboration

Figure 1. Screening results.

Table 3. Final set of documents selected by database.

DATABASE	Articles	Conference Papers	Total
SCOPUS	14	62	76
WOS/SCOPUS	98 (*)		98 (*)

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WOS	1 (**)		1 (**)
TOTAL	113	62	175

Source: Own elaboration. (*)50 extra publications found in both Scopus and WOS databases. (**) Kiatlertnapha and Vorayos 2017 [21].

2.5. Extract and report

As in Safarzadeh et al. [18], different aspect of the articles selected were examined, focusing on top authors, journals, disciplines, citations, countries, institutions and main EC determinants. The Software VOSviewer (VOS) [22] and CiTNetExplorer (CNE) [23] were utilized to examine the papers. The following sections report the results from the information analyzed.

3. Results

This section explores relevant aspects of the documents selected. Bibliometric data are analyzed in order to understand core characteristics of the papers studied. Additionally, selected papers are scrutinized to determine factors affecting EC in HEIs.

3.1. Sources and Disciplines

In order to answer the first research question, the 175 articles chosen were analyzed to identify the different publishing sources and the involvement of different academic disciplines. The aforementioned documents were published in 103 different sources, encompassing 57 journals, 42 conference proceedings and 4 book series. Table 4 displays the most common sources used for publishing the articles selected.

Table 4. Top journals for EC in HEIs.

Source Title	**SOURCE TYPE**	**Publisher**	**Articles selected**	**Share of 175**	**Subject Area**	**SJR BEST QUARTILE (SCOPUS)**	**JIF Best Quartile (WOS)**
Energy and Buildings	Journal	Elsevier	24	13.7%	Engineering	Q1	Q1
International Journal of Sustainability in Higher Education	Journal	Emerald	9	5.1%	Social Sciences	Q1	Q1
Sustainability	Journal	MDPI	7	4.0%	Computer Sciences; Engineering; Energy; Environmental Sciences; Social Sciences	Q1	Q2
Journal of Cleaner Production	Journal	Elsevier	6	3.4%	Business Management; Energy; Engineering; Environmental Sciences	Q1	Q1
Energies	Journal	MDPI	6	3.4%	Energy; Engineering; Mathematics	Q1	Q3
Applied Mechanics and Materials	Book Series	Trans Tech Publications Ltd.	4	2.3%	Engineering	N/A	N/A
Energy Policy	Journal	Elsevier	4	2.3%	Energy; Environmental Science	Q1	Q1

Advanced Materials Research	Book Series	Trans Tech Publications Ltd.	3	1.7%	Engineering	N/A	N/A
Energy Procedia	Conference Proceedings	Elsevier	3	1.7%	Energy	N/A	N/A
E3S Web of Conferences	Conference Proceedings	EDP Sciences	3	1.7%	Earth and Planetary Sciences; Energy; Environmental Science	N/A	N/A
Smart Innovation, Systems and Technologies	Book Series	Springer Nature	3	1.7%	Computer Sciences; Decision Sciences	Q3	N/A
IOP Conference Series: Earth and Environmental Science	Conference Proceedings	Institute of Physics Publishing Ltd.	3	1.7%	Earth and Planetary Sciences; Environmental Science	N/A	N/A

Source: Own elaboration based on WOS and Scopus data extracted on 11-10-2022.

In order to assess the concentration of journals publishing papers about the studied topic, authors use the Herfindahl-Hirschman Index (HHI). This index is widely used to measure market concentration and competitiveness. It was applied by Moschini et al. (2020) in a bibliometric study to analyze the level of multidisciplinarity in academic production. It is calculated according to equation (1).

$$HHI(v) = \sum_{i}^{n} {v_i}^2 \qquad v_i \in V \tag{1}$$

Here, V corresponds to a vector containing the percentage of articles published in n Journals, Conference Proceedings or Book Series. HHI takes values from 0 to $(1-\frac{1}{n})$. The closer to zero the value, the less concentrated the vector studied. According to the regulation of the US Department of Justice (when applied to markets) an HHI ≤0.1 denotes competitiveness and unconcentrated areas, 0.1 <HHI ≤ 0.18 is classified as moderately concentrated and HHI>0.18 represents a highly concentrated sector [24].

This definition was applied to assess the level of concentration among the 103 sources publishing documents about EC in Universities. The HHI takes a value of 0.032, denoting an unconcentrated selection of sources.

The analysis of the disciplines involved in the selected documents clarifies whether the topic has been studied using a multidisciplinary approach. As mentioned in the introduction, efforts to reduce EC in Universities entail not only technical initiatives such as improving the efficiency of buildings, but also sociological aspects such as raising awareness of energy use among students. Therefore, articles addressing this topic are expected to incorporate both social sciences and exact sciences. Graph 2 shows the subject areas (disciplines) of the 175 documents selected, according to the Scopus classification[2]. It is important to mention that articles inherit the subject area assigned by Scopus to their publishing sources [16]; therefore, it is assumed that papers are published in journals which properly mirror their characteristics in terms of discipline orientation.

[2] The only document in the sample that is not available in the Scopus database is categorized in WOS as "Social Science interdisciplinary" is Kiatlernapha and Vorayos [21]. Therefore, it is classified in the Scopus subject area "Social Science".

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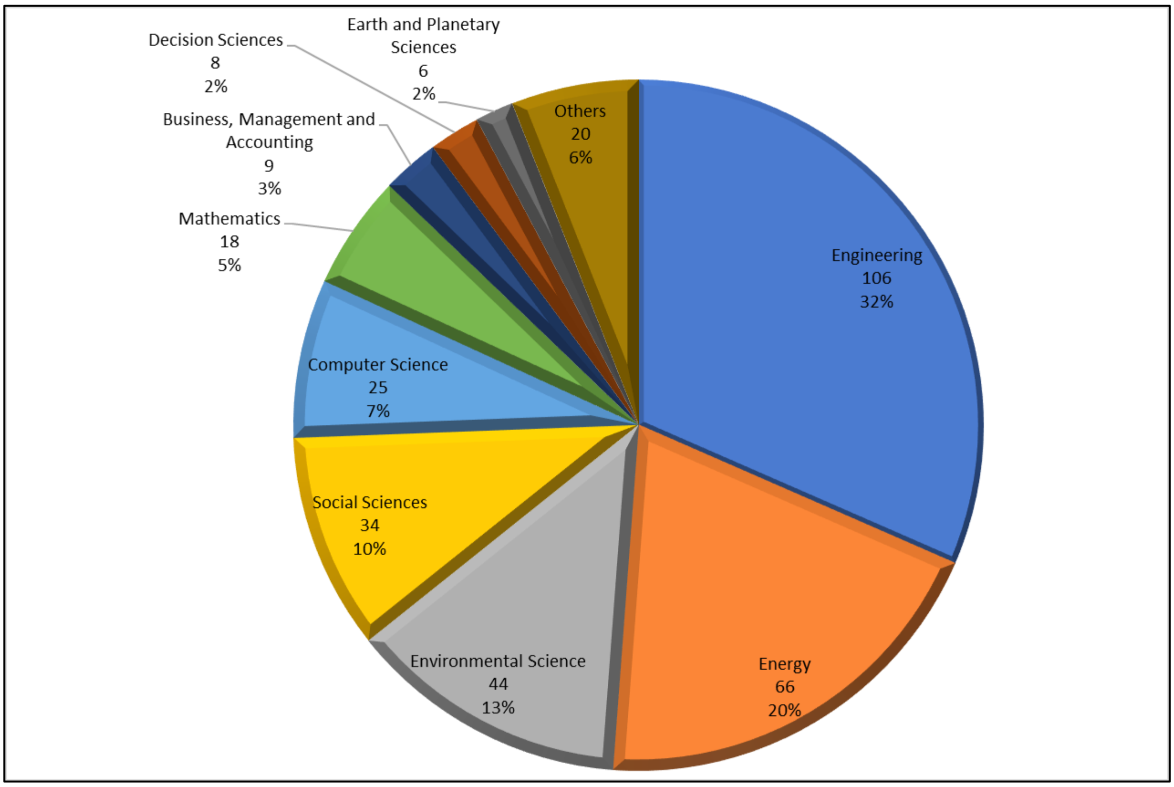

Source: Source: Own elaboration from WOS and Scopus extracted on 10-25-22

Others: Chemical Engineering, 4 (1%), Physics and Astronomy, 4 (1%), Material Science, 3 (1%), Arts and Humanities, 2 (1%), Economics, Econometrics and Finance, 2 (1%), Medicine, 2 (1%), Multidisciplinary, 2 (1%), Agricultural and Biological Sciences, 1 (0.3%)

Graph 2. Categorization of subject areas[3] of the selected documents.

Engineering and Energy are the leading subject areas among the selection of papers, denoting a bias towards technical disciplines in this research field. Conversely, there is a scarcity of documents in the broad area of social sciences/humanities. This suggests that the social sciences encompass knowledge gaps worth investigating on EC in HEIs, possibly related to students' attitudes towards energy use.

The documents selected show the involvement of several disciplines, with 90 out of 175 articles (51%) covering more than one subject area (1.92 areas per document on average). The most repeated overlap occurs between Engineering and Energy, followed by Environmental Science with Energy (Appendix C displays the co-occurrence matrix) This indicates that the multidisciplinarity in this field is sought through the combination of exact sciences, but it is not generally attained through extension to the social sciences.

To further assess the multidisciplinarity among the selected papers, the HHI for the subject areas was determined[4]. The index takes a value of 0.176, which denotes an unconcentrated pool of disciplines, albeit close to the limit of being deemed moderately concentrated.

3.2. Leading Countries, Universities and Authors

To answer research question 3, we have to identify the leading countries in terms of scientific research about this subject. It is important to note that the total scholarly output (all topics) is heterogeneous in terms of countries' contributions, with the USA responsible for 25% of the papers, followed by China with 17% (WOS Database, 2008-2022). Given this, the analysis of leadership in

[3] An article might be assigned by Scopus to more than one subject area.

[4] An article can be assigned to more than one discipline.

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research on EC in Universities should be undertaken not only in absolute terms, but also by studying the deviations between the productivity in this topic and the total output of academic articles.

The set of selected articles includes affiliations to 49 different nations. Table 5 displays the leading countries (three or more articles) among the papers selected, and their percentage contribution to the set of selected articles. These values are compared with countries' percentage contribution to all articles (26,345,327) indexed in the WOS Database (2008-2022) and all documents (45,339,374) in the Scopus Database (2006-2022) in the same time span as that for the selected publications. Table 5 is ordered by the number of articles selected from the Scopus database, since it contains 174 of the 175 documents selected, with this value being a proxy for the total contribution of each country[5].

Table 5. Articles per country within the selected papers[6].

	WOS			SCOPUS		
Country	**Articles selected**	**Share of Selected Articles**	**Share of total Scholarly output (*)**	**Articles selected**	**Share of Selected Articles**	**Share of total Scholarly output (**)**
USA	15	15%	25%	26	15%	23%
CHINA	15	15%	17%	25	14%	17%
UNITED KINGDOM	15	15%	8%	18	10%	7%
SPAIN	10	10%	4%	12	7%	3%
BRAZIL	6	6%	3%	11	6%	2%
ITALY	6	6%	4%	11	6%	4%
MALAYSIA	2	2%	1%	11	6%	1%
PORTUGAL	9	9%	1%	10	6%	1%
AUSTRALIA	7	7%	4%	8	5%	3%
GREECE	3	3%	1%	7	4%	1%
CANADA	4	4%	4%	6	3%	4%
SOUTH AFRICA	3	3%	1%	6	3%	1%
HONG KONG	0	0%	1%	5	3%	1%
GERMANY	2	2%	6%	4	2%	6%
JAPAN	2	2%	5%	4	2%	5%
NIGERIA	1	1%	0%	4	2%	0%
SAUDI ARABIA	3	3%	1%	4	2%	1%
SOUTH KOREA	2	2%	3%	4	2%	3%
MEXICO	2	2%	1%	3	2%	1%
ROMANIA	1	1%	1%	3	2%	0%
RUSSIAN FEDERATION	0	0%	3%	3	2%	2%
TURKEY	0	0%	2%	3	2%	1%

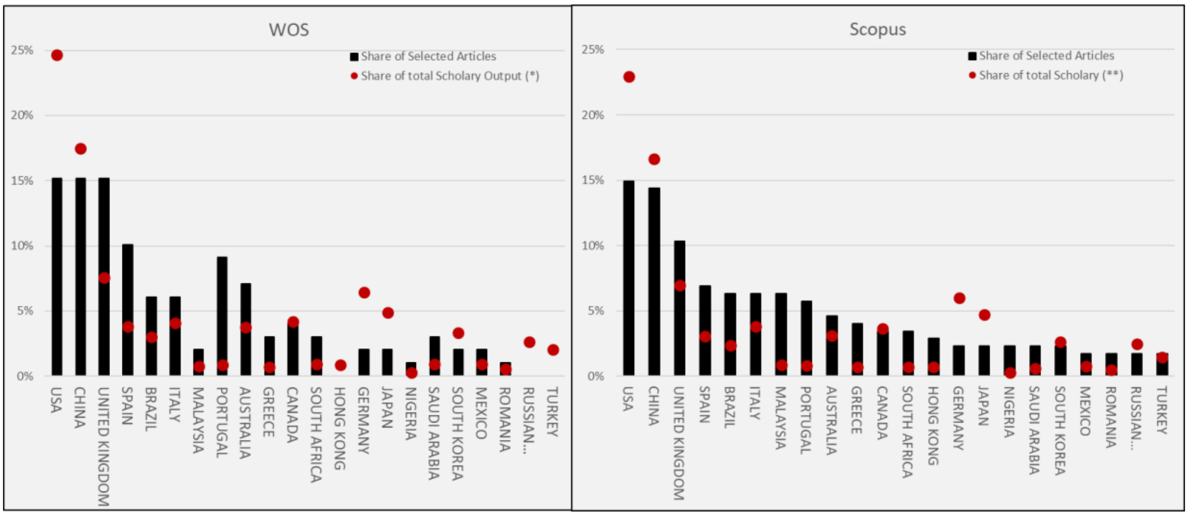
Source: Own elaboration from WOS and Scopus data extracted on 10-15-22 and 10-23-22. (*) 26,345,328 articles. (**) 45,339,374 Documents.

As can be seen in Table 5, the USA, China and UK are the leading countries for articles related to EC in Universities. This either reflects a particular scientific interest in the topic or is a consequence

[5] Kiatlertnapha and Vorayos [21] is assigned to Thailand.

[6] A single article could be assigned to more than one country, so the sum of all the percentages adds up to more than 100%.

of the countries' scholarly capabilities. Consequently, we studied the percentage gap between each countries' contribution to the set of selected articles and their respective share of total publications in the period, which is shown in Graph 3.



Source: Own elaboration from WOS and Scopus data extracted on 10-15-2022 and 10-23-2022

(*) 26,345,328 articles

(**) 45,339,374 Documents

Graph 3. Gap between share of total scholarly output and share of selected articles7.

As displayed in Graph 3, the USA's share of the 99 selected WOS articles (15%) is lower than their share of total WOS publications (25%); the same can be said for the Scopus database. On the other hand, some countries have a higher share in the set of selected documents about EC in Universities than they do in total scholarly output; most notably, Portugal, the UK, Spain, Australia (WOS), Brazil and Malaysia (Scopus). This suggests a particular interest in the topic in those countries.

The HHI was calculated according to each country's share in the articles selected about this subject. It takes a value of 0.052, denoting an unconcentrated environment. This is consistent with the leading countries (USA and China) having a lower share than they have in total scholarly output, indicating that the production on this topic is more evenly distributed among countries.

It is found that 38 out of the 175 (22%) reviewed papers involve international collaboration, and the UK is the leading country in this regard. The number of articles written with international collaboration is shown Table 6, and the total co-occurrence matrix is displayed in Appendix D.

Table 6. Internationally collaborative publications.

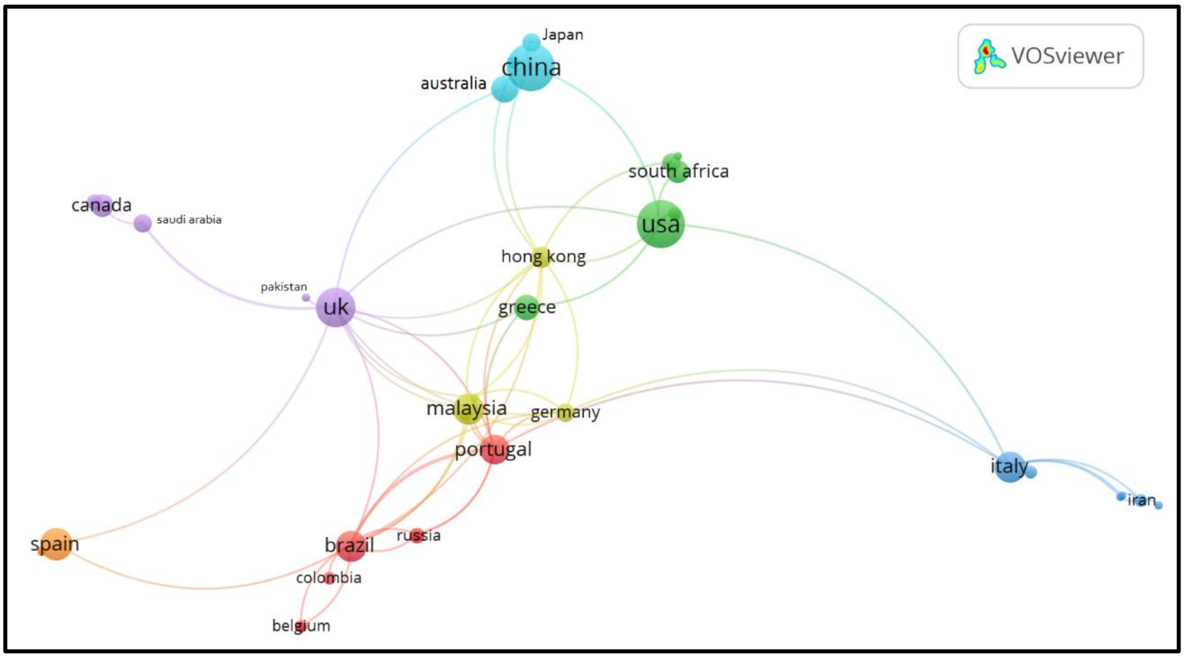
Country	TOTAL PUBLICATIONS (*)	INTERNATIONAL COLLABORATION	%
United Kingdom	18	7	39%
United States	26	6	23%
China	25	6	24%
Brazil	11	6	55%
Italy	11	5	45%
Portugal	10	5	50%

[7] One article could be assigned to more than one country, so the sum of all the percentages adds up to more than 100%

Australia	8	5	63%
Spain	12	4	33%
Hong Kong	5	4	80%
Nigeria	4	3	75%
Saudi Arabia	4	3	75%

(*) Within the 174 Scopus selected articles. Three or more internationally collaborative documents. Source: Own elaboration from Scopus data extracted on 10-27-2022.

Co-authorship among different countries is examined with the analytical Software VOS, (Figure 2). The resulting map is based on the 174 publications housed in the Scopus database, in order to cover 99% of the set of publications selected[8].



Source: Own elaboration utilizing VOSviewer

Figure 2. International collaboration map of the 174 Scopus papers.

Maps provided by VOS are classified as distance-based maps, since the closeness of the items to one another reflects the strength of the relationship between them. The size of the label and its circle denotes the importance of an item [22]. In this case, label size indicates the number of papers corresponding to a certain country. Colors indicate the clusters to which each country was allocated by the software. Seven clusters are identified by the analysis, with the top six countries contributing to the set of articles (the USA, China, the UK, Spain, Brazil, Italy and Malaysia) all being assigned to different clusters. Portugal and Brazil are situated at close proximity in the map, within the same clusters. Also, these two countries have collaborated with each other in three publications (the highest number among the papers selected) (Appendix D) .This international collaboration is a factor that explains both Portugal's and Brazil´s overrepresentation in this topic when compared to overall academic output (see Table 5). This is because international collaboration leverages academic production.

In order to identify leading Universities researching EC in HEIs, Scopus and WOS data about authors' affiliations was restructured. The reason for doing so is because this information is often

[8] VOS works with WOS and Scopus files, but separately. We chose to use the broader Scopus set of documents.

presented in terms of departments or colleges; therefore, it was transformed to denote Universities or research institutes.

Table 7 displays the top institutions[9] researching EC in Universities according to authors´ affiliation. Additionally, the table includes the 2023 Times Higher Education Ranking [25] to provide information on how these institutions are placed within the global landscape of Universities.

Table 7. Top institutions according to authors' affiliation (3 or more articles).

University	Country	Time Higher Education Rank 2023	1st Author		TOTAL	
			WOS	**SCOPUS**	**WOS**	**SCOPUS**
University of Sheffield	United Kingdom	114	4	5	5	6
Universiti Teknologi Malaysia	Malaysia	601-800	0	4	0	5
Griffith University	Australia	251-300	4	4	4	4
Universitat Politècnica de Catalunya	Spain	801-1000	2	3	2	4
Polytechnic University of Turin	Italy	601-800	1	3	2	4
South China University of Technology	China	401-500	1	1	1	4
Universiti Tun Hussein Onn Malaysia	Malaysia	1201-1500	1	4	1	4
University of Passo Fundo	Brazil	1501+	1	3	2	4
University of Coimbra	Portugal	601-800	3	3	3	3
University of Lisbon	Portugal	501-600	2	2	2	3
Democritus University of Thrace	Greece	1201-1500	1	3	1	3
National Autonomous University of Mexico	Mexico	1001-1200	1	2	2	3
Universidade da Beira Interior	Portugal	801-1000	1	2	2	3
University of California, Berkeley	USA	8	1	1	3	3
University of Naples Federico II	Italy	351-400	1	3	1	3
Universiti Malaysia Kelantan	Malaysia	1201-1500	0	0	0	3
University of Bergamo	Italy	801-1000	0	0	1	3
University of Florida	USA	151	0	3	0	3
University of Molise	Italy	-	0	0	1	3

Source: Own elaboration from WOS, Scopus and Times Higher Education Ranking data extracted on 4-27-22 and 11-14-22.

Overall, 237 organizations participated in the 175 papers studied (an average of 1.35 institutions per document), with 91 publications being indexed under more than one organization, as displayed Table 8. The wide range of institutions investigating this topic gives rise to a fragmented distribution, which is characterized by an HHI of 0.006.

Table 8. Co-authorship distribution among organizations.

Number of Organizations in Collaboration	Articles
2	62
3	16
4	8
5	3

[9] An article can be indexed under more than one organization.

6	1
7	0
8	0
9	1

Source: Own elaboration from WOS and Scopus data extracted on 4-27-22.

Research question 2 also requires the analysis of authors' influence. This is analyzed by the number of articles published by scholars, the number of citations their articles have received and by a citation network which displays the academic influence between authors.

The set of 175 publications under analysis includes a total of 576 different authors (an average of 3.3 per document). Some authors participated in more than one publication, which demonstrates their particular interest in this area. This is displayed in Table 9, ordered by the number of publications contained in the Scopus Database. Zhonghua Gou is the most prolific author that appears in the set of documents selected, with four articles simultaneously housed in both databases; nevertheless, this author is not listed as the first author in any of the selected publications. In terms of concentration among authors researching this topic, the environment can be described as competitive and even fragmented, since the HHI has a value of 0.002.

Table 9. Authors with three or more of the 175 selected articles.

	1st Author		Total	
Author	**WOS**	**Scopus**	**Wos**	**Scopus**
Gou Z.	0	0	4	4
Ishak M.H.	0	3	0	4
Altan H.	1	2	2	3
Borrelli M.	0	0	0	3
Brandli L.L.	0	0	2	3
De Masi R.F.	0	0	0	3
Gui X.	3	3	3	3
Sapri M.	0	1	0	3
Sipan I.	0	0	0	3
Su Y.	0	3	0	3
Vanoli G.P.	0	0	0	3
Zhang L.	0	1	0	3

Source: Own elaboration from WOS and Scopus data extracted on 10-15-22 and 10-25-22. 99 articles only in WOS. 174 articles in WOS and Scopus simultaneously. 175 total articles.

The citations received by an article is an indicator of the academic influence exerted on other authors. Table 10 displays the top ten analyzed articles according to the number of citations received. Average citations per year is presented as a complementary indicator.

Table 10. Top 10 citations ranking of selected papers.

	Title	**Year**	**WOS**		**SCOPUS**		**Author**
			Total Citations	**Average Citations Per Year**	**Total Citation**	**Average Citation Per Year**	
1	Understanding the energy consumption and occupancy of a multi-purpose academic building	2015	169	21	217	27	Gul and Patidar [26]

2	Potential opportunities for energy conservation in existing buildings on University campus: A field survey in Korea	2014	93	10	112	12	Chung and Rhee [27]
3	Occupancy diversity factors for common University building types	2010	89	7	102	8	Davis and Nutter (2010) [28]
4	Application of an energy management and control system to assess the potential of different control strategies in HVAC systems	2010	75	6	96	7	Escrivá-Escrivá et al. [29]
5	Development of green campus in China	2014	76	8	87	10	Tan et al. [30]
6	Energy use characteristics and benchmarking for higher education buildings	2018	46	9	55	11	Khoshbakht et al. [31]
7	Effectiveness of daylighting design and occupant visual satisfaction in a LEED Gold laboratory building	2011	49	4	53	4	Hua et al. [32]
8	A variation focused cluster analysis strategy to identify typical daily heating load profiles of higher education buildings	2017	47	8	52	9	Ma et al. [33]
9	Development of a web based energy management system for University Campuses: The CAMP-IT platform	2016	42	6	51	7	Kolokotsa et al. [34]
10	Energy saving on campus: A comparison of students' attitudes and reported behaviours in the UK and Portugal	2016	42	6	51	7	Cotton et al. [35]

Source: Own elaboration from WOS and Scopus data extracted on 10-15-22 and 10-25-22.

As some authors have contributed multiple publications to the set of documents selected, total citations received per author can be examined. This information is presented in Table 11.

Table 11. Top 20 authors according to citations received.

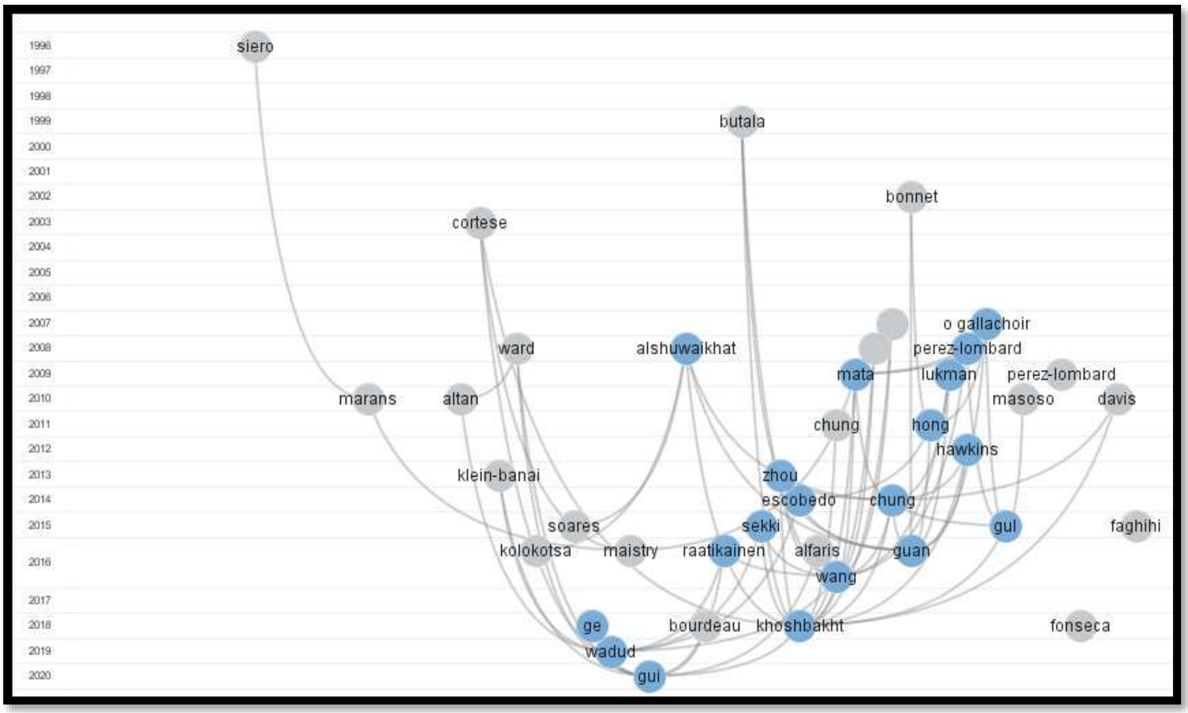
Author	1st Author		Total		Publications
	WOS	Scopus	WOS	Scopus	(*)
Gul M.S.	169	217	169	217	1
Patidar S.	0	0	169	217	1
Chen S.	0	0	113	135	2
Chung M.H.	93	112	93	112	1
Rhee E.K.	0	0	93	112	1
Davis III J.A.	89	102	89	102	1
Nutter D.W.	0	0	89	102	1
Nord N.	0	0	84	100	2
Alcázar-Ortega M.	0	0	75	96	1
Escrivá-Escrivá G.	75	96	75	96	1
Segura-Heras I.	0	0	75	96	1
Wang L.	0	5	76	92	2
Shi Q.	0	0	76	87	1
Tan H.	76	87	76	87	1
Gou Z.	0	0	67	80	4
Altan H.	37	40	64	70	3
Srebric J.	0	0	63	70	2
Brandli L.L.	0	0	47	62	3

Dupre K.	0	0	46	55	1
Khoshbakht M.	46	55	46	55	1

Source: Own elaboration from WOS data extracted on 10-15-2022 and 7-22-2022. (*) within the 175 selected.

Even though Mehreen S. Gul, contributed only one article to the set of selected publications, this author still leads in terms of citations, both as first author and overall. Moreover, among the top 20 authors in terms of citations, only seven of them have contributed more than one publication to the set of chosen articles. It can thus be seen that multiple publications do not necessarily lead to a higher number of citations received.

The academic influence between authors can be represented through a citation network with the assistance of CNE software. This computer-based tool displays and analyzes citation networks of articles [23] using (only) information extracted from the WOS database. CNE is thus utilized to create a citation network based on the 99 WOS articles selected. The final citation network consists of a total of 120 publications as it includes 21 extra articles citated by at least five of the original 99 WOS research papers. CNE ranks publications according to an indicator called the "citation score" which accounts for the number of citations within the network being studied. Figure 3 presents the citation network displaying the 40 publications with the highest citation scores. Table 12 presents the top publications according to their citation score, with Chung and Rhee [27] being the most cited article (of the 99 WOS publications selected) in the citation network.



Source: Own elaboration using CiteNetExplorer

Figure 3. Citation network.

Table 12. Top publications according to their citation score.

Title	Citation Score	Type	Authors
Potential opportunities for energy conservation in existing buildings on University campus: A field survey in Korea	19	Internal	Chung and Rhee [27]
An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices	14	External	Alshuwaikhat and Abubakar [36]
A review on buildings energy consumption information	12	External	Pérez-Lombard et al. [37]

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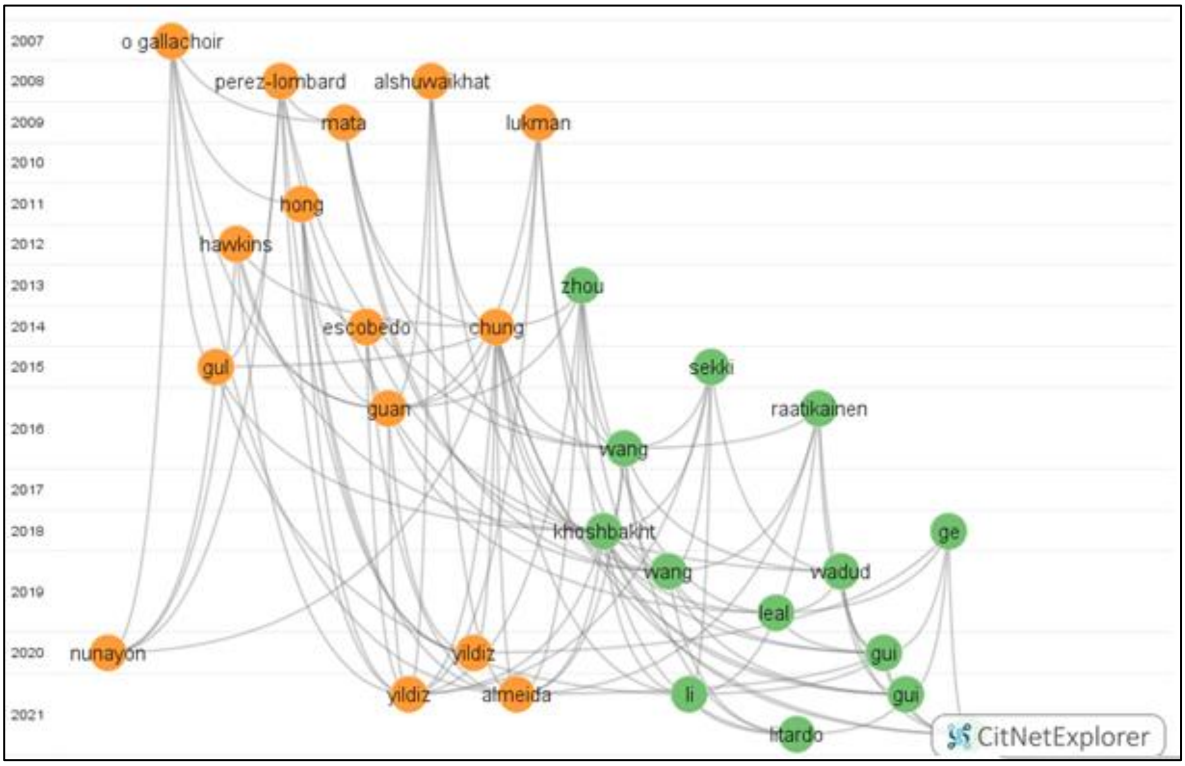
Energy use characteristics and benchmarking for higher education buildings	12	Internal	Khoshbakht et al. [31]
Determinants of energy use in UK higher education buildings using statistical and artificial neural network methods	10	External	Hawkins et al. [38]
Sector review of UK higher education energy consumption	9	Internal	Ward et al. [39]
Survey of energy consumption and energy conservation measures for colleges and Universities in Guangdong province	9	Internal	Zhou et al. [40]
Energy consumption and GHG emission scenarios of a University campus in Mexico	9	Internal	Escobedo et al. [41]
Understanding the energy consumption and occupancy of a multi-purpose academic building	7	Internal	Gul and Patidar [26]

Source: Own elaboration using CNE. Internal= Within the 99 WOS articles selected. External= citated by at least five of the original 99 WOS research papers.

As in the study by van Eck and Waltman [23], core publications were defined as those having citation relations with at least five other core articles. A total of 29 core publications were identified, 19 of which are displayed in blue in Figure 3. Interestingly, the article by Alshuwaikhat and Abubakar [36] has a high citation score, even though it is an external publication (not included in the 99 selected articles). This article focused on campus sustainability influenced articles ranked 2nd (Chung and Rhee, [27]) and 6th Khoshbakht et al.,[31]) in Table 10. The citation network was reduced to a sub-net formed only by the 29 core publications. CNE identifies two clusters according to the citations relation among articles (see Figure 4).

The earliest publications in the first cluster (orange) are external: Gallachóir et al. [42], Pérez-Lombard et al. [37] and Alshuwaikhat and Abubakar [36]. The first two of these papers are directly linked with Gul and Patidar [26], which is the most cited article among the 175 publications selected. In the other cluster (green), the oldest publication is Zhou et al. [40], while Sekki et al. [43] and Raatikainen et al.[44] are external publications which exert influence in this group.



Source: Own elaboration using CiteNetExplorer

Figure 4. Sub-net of core publications.

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3.3. Factors Driving EC in Universities

Answering research question 3 requires the exploration of factors driving EC in HEIs. It is important to note that papers often mention multiple factors. Table 13 represents the main determinant of EC in HEIs according to the documents studied. The results obtained do not differ from those found in the literature for buildings serving other sectors [45–47].

Table 13. Main consumption factors mentioned in the selected articles.

Factor	Type of Factor	Number of Selected articles mentioning the Factor
Heating, Ventilation, and Air Conditioning Systems	Technical	69
Occupancy Factors (Patterns/Total)	Behavioral	59
Climate	Climatic	52
Building Function	Institutional	40
Lighting Systems	Technical	39
Occupant Behavior	Behavioral	23
Equipment/Electronic Devices	Technical	17
Gross Floor Area	Institutional	17
Building Age	Technical	15
Research intensity/Discipline Orientation	Institutional	14
Building Design	Technical	13
Building Envelope	Technical	10

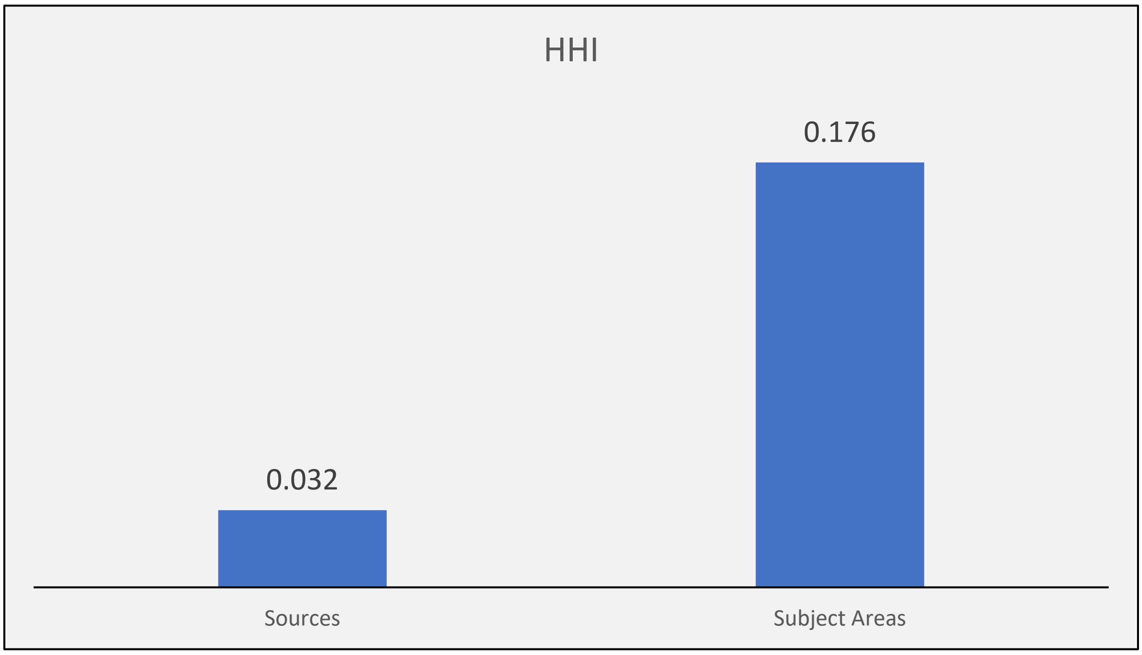
Source: Own elaboration.

These factors are often interrelated and will be discussed in section 4.3 .

4. Discussion

4.1 Sources and disciplines

The analysis of leading sources and disciplines has proven useful for determining the main characteristics of the papers selected. The 175 articles were published in 103 different sources, 82 of which provided only one article. This unconcentrated scenario is reflected in the HHI when applied to the pool of sources, as it displays a value of 0.032. Nevertheless, when calculating the HHI for the subject areas in which the documents are classified, the value of the index jumps to 0.176. The important rise in the HHI when shifting from sources to subjects areas (see Graph 4) indicates that the selection of journals, conference proceedings and book series for publishing the articles was not random. Even though there is wide dispersion among sources, the spread of subject areas is narrower. This indicates that authors focus on a specific set of disciplines and that the selection of sources is a consequence of the subject areas involved, with scholars selecting sources according to their stated discipline orientation.



Source: Own elaboration

Graph 4 HHI comparison between sources and journals.

Since EC in Universities is driven by behavioral, climatical, institutional and technical factors (see Table 13), there is a need to involve multiple disciplines when researching this topic. The analysis points to an unconcentrated set of disciplines, although the HHI is close to reaching the limit that indicates moderate concentration (0.18). This analysis assumes that financial market classifications according to the HHI are applicable to this topic. Comparable values were reported in the study of Moschini et al. [16]. Those authors collected a sample of articles by researchers at the Italian Institute of Technology, which was expected to be multidisciplinary, scoring an HHI of 0.06. This was compared with the National Institute of Physics, which is less multidisciplinary as it focuses on a specific science. It scored an HHI of 0.29, denoting high concentration among the subject areas covered by its researchers. The HHI for the disciplines included among the articles analyzed in this study lays between the aforementioned values (and close to the limit of moderate concentration), indicating a moderate degree of multidisciplinarity but room for some disciplines to achieve greater preponderance. We refer specifically to the social sciences. This is because HEIs are complex systems, where human interactions shape the important aspects of academic activities; thus, analyses of phenomena occurring in these institutions should incorporate this scientific area.

4.2. Leading countries, Universities and authors

HEIs face important challenges in terms of adapting to changes in the energy sector [48], in terms of future higher costs and sustainable behavior. Therefore, the analysis of leading countries, Universities and authors investigating this topic reveals where the scientific foundations needed to address the predicted changes are being laid, and by whom.

The leading countries investigating this topic are the USA and China (followed by the UK). Since these are the main countries in terms of overall academic output, their leading role in exploring EC in Universities can be attributed to their more advanced research capabilities. On the other hand, there are countries whose share of the scholarly output on this subject surpasses their share of total output (Australia, Brazil, Malaysia, Portugal, the UK, and Spain). We point to a combination of three factors that can explain this situation: 1) there is a particular interest in investigating this matter in these countries; 2) the EU's stringent environmental regulation and strategic objective of reducing

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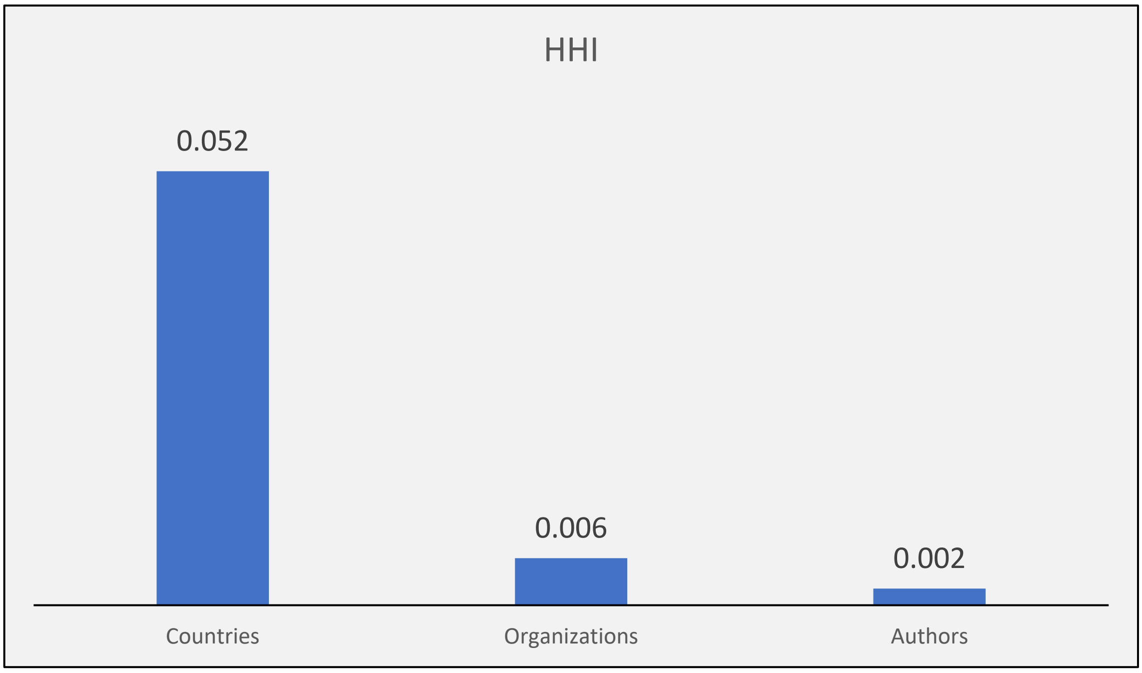
emissions [49,50] has become a motivating factor for British,[10] Portuguese, and Spanish researchers; and 3) international collaboration helps to leverage countries' scholarly output, which boosts Australian, Brazilian, British, Portuguese, and Spanish academic output on this matter (see Table 6 and Figure 2).

The analysis of leading institutions reveals that the University of Sheffield is the most prolific. However, its leading margin is small, and its prominent position should be examined over a longer period. In terms of the organizations that have contributed articles to the set of 175 documents selected, we find not only Universities but also governmental institutions. China's Ministry of Education participated in the publication of two articles [51,52], whereas Greece's Ministry of Education collaborated on one [53], underlining the political concern about the topic studied.

Zhonghua Gou is the most fruitful author on this subject. Nevertheless, this scholar is not indexed as first author in any of his four publications about this mater. Therefore, his leadership status depends on the criteria used in those publications to display the order of the authors. On the other hand, the analysis of citations indicates a prominent role for Mehreen S. Gul and Sandhya Patidar, whose paper is by far the most cited one, which gives them an unquestionable leadership status.

Finally, in terms of HHI, countries, Universities (organizations) and authors are described as unconcentrated environments (see Graph 5). Countries present an HHI almost one order of magnitude superior to that of organizations and authors. This is consistent with the finding that only 49 different countries are included in the selected articles, whereas there are 237 different organizations and 576 authors, forming much more fragmented environments.



Source: Own elaboration

Graph 5 HHI comparison between countries, organizations and authors**.**

[10] The United Kingdom left the EU in 2020.

4.3. Factors

4.3.1. Behavioral Factors

Management is mentioned by some authors as a factor that fosters energy savings. In order to advance towards an energy friendly campus, effective leadership and management involvement are critical [30]. It is essential for HEIs to demonstrate their willingness to implement and support sustainable policies before asking students and lecturers to change their behavior [54]. In this sense, effective environmental management within HEIs has a double effect; it not only seeks to establish a green, energy-saving campus, but also encourages all stakeholders to change their environmental behavior. Managers should address several issues to develop a culture focused on reducing EC. They are responsible for raising awareness and fostering participation among the college community and for developing a robust energy management team [55]. Particularly, the administrators should focus on reducing energy wastage, bearing in mind that it occurs because of the lack of awareness among staff and students, often combined with the absence of managerial guidelines [56].

The results shown in Table 13 stress the importance of **Occupant Behavior** as a factor driving EC in HEIs, as it has been mentioned in 23 articles. Universities host a huge number of students, lecturers, administrative workers, and guests, whose different energy utilization habits have a significant impact on EC [57]. The impact of occupants' actions and behavior has been found to strongly affect the energy performance of HEIs´ buildings [58]. Put simply, "buildings don't use energy, people do" [59], and HEIs are no exception. Moreover, a correlation was found between occupant behavior and EC by comparing a normal situation with an altered situation in which electricity consumption was 9% lower [8]. This shows that user behavior can be influenced to foster energy savings. Among the selected articles, examples were found of how occupant behavior influences EC, such as people's tendency to bring their personal electric equipment to campus [60] and the unwillingness to shut down PCs or turn off lights and audio-visual devices [26]. This highlights the importance of management involvement in the normative aspect of occupants' conduct, with behavior assessment being a task that facilities managers must undertake [61], especially considering the savings that might be achieved by raising awareness. Furthermore, gathering data about users' conduct and its influence on energy use is crucial to develop an effective strategy for energy management [62]. Similarly, it is important to analyze how students' attitudes differ depending on their countries of origin and gender. These variables have an impact on EC [35], emphasizing the importance for managers to understand factors explaining diverse energy use behavior among users.

The number of students, lecturers and employees attending University buildings over a year presents important seasonal fluctuations. Consequently, **Occupancy** is a factor that must be considered when analyzing EC in HEIs. Summer breaks tend to be common while winter breaks are more frequent in some countries. The relationship between the number of occupants in different periods and EC is suggested in 59 of the 175 papers studied (see [63,64]). Indeed, several authors have recently studied the impacts of Covid-19 lockdowns on EC in HEIs, noting that even though there is a baseline energy demand, the absence of staff and students reduced consumption significantly. In that regard, occupation analysis helps to uncover inefficiencies in energy utilization (see [65], for the specific case of the Aristotle University of Thessaloniki). Subsequently, if EC does not drop during lower occupancy periods, administrators can foster energy savings by analyzing inefficiencies attributed to high baseline consumption (probably due to research activities) or to careless user behavior.

4.3.2. Institutional Factors

Building Function is the fourth most mentioned factor affecting EC (Table 13). University buildings host different activities, which produce diverse impacts on the overall energy utilization [66]. This heterogeneous type of edifices varies from traditional teaching premises and residential services to hospitals and research laboratories [67], which suggests the importance of classifying the different buildings' functions when analyzing EC. Khoshbakht et al. [31] established several building categories and calculated both total EC per edifice and their Energy Use Intensity (EUI), which denotes the energy usage of a building relative to its area and is expressed as the consumption per square meter per year [68]. Results indicate that libraries consume more energy than other types of buildings (as they often use a large proportion of gross floor area), whereas EUI values are higher in research buildings. Similar findings were provided by Gui et al. [69], with teaching buildings accounting for high use of total electricity, while research buildings had the highest EUI [70,71]. For the specific case of research equipment in Stanford University campus, see [72].

Data centers constitute a specific case of energy intensive buildings, as they use around 25% and 50% more energy per gross floor area than regular office spaces [1]. In Universities which have not outsourced their data centers, buildings containing specialized IT equipment tend to be the most intensive energy consumers, alongside hospitals [73].

Gross Floor Area of buildings is a parameter that strongly affects energy utilization, as gas and electricity consumption have a direct relation to the size of the edifices [27,74]. Although Gross Floor Area is an important factor, it is mentioned in only 17 papers (see Table 13), given that most authors analyzed EC in terms of EUI. Interestingly, some authors propose the existence of some economies of scale between Gross Floor Area and EC, with larger HEIs being more energy efficient and displaying lower EUI values [13].

According to Table 13, the **Research Intensity Level** of HEIs and their **Discipline Orientation** are factors that affect or explain EC. These factors are often interrelated in terms of their effect on energy intake, both determining the need for energy-intensive equipment and laboratories. Universities present differences in their EUI according to their discipline classification, with those oriented to exact sciences being more energy intensive than those associated with the humanities [31,40,75]. The University of Thessaly is an interesting example in this regard [76]. Similarly, research-intensive Universities usually utilize more energy than teaching-focused ones [13] because laboratories have high EUI; indeed, correlations between research activities and EC have been established by Wang [77]. Overall, this suggests that research activities generate externalities in terms of EC and environmental impact, which must be addressed.

4.3.3. Climate

Local Climate is one of the most commonly mentioned factors among the selected papers (see Table 13), with weather affecting EC by regions [69], and through different parameters such as temperature, humidity, and visibility [78]. Several authors have established correlations between weather characteristics and EC. Interesting cases in this regard have been presented by Heidarinejad et al. [79] concerning Penn State University and Harvard. Hot weather environments tend to demand high amounts of energy to maintain a comfortable indoor temperature; therefore, June is the peak energy consuming period in the northern hemisphere for Universities located in hot weather zones [5], such as California [53], Saudi Arabia [80] and Hong Kong [67]. At the other extreme, as expected, the more pressing issue for HEIs in cold climates is energy demand for heating [81], which also leads to high EC scenarios. This analysis raises the question whether governments should encourage the establishment of Universities in mild weather regions, or conversely, whether HEIs located in zones of extreme climate should be subsidized to help them handle the higher expenditure on energy resources.

4.3.4. Technical Factors

Although **Building Design** is only mentioned as an EC driver in 13 articles, some authors consider it relevant (see [82]). Indoor environmental comfort and illumination are factors that determine energy utilization which are dependent on the orientation and size of buildings [83]. The number, shape and surface area of windows should be analyzed thoughtfully as there is a compromise to be reached between thermal and lighting requirements [27] . Overall, energy saving strategies should be examined at the planning stage of a building development project to achieve

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energy savings goals [52], considering research requirements and discipline orientation. Also related to the early stages of building design, **Building Envelope** is a characteristic addressed by 10 authors studying this topic, and one which merits careful consideration.

Building Age is a factor influencing EC that has been mentioned in 15 articles. Newer buildings tend to have lower EUI due to better lighting and thermal insulation standards, and more efficient systems [84–86]. Nevertheless, there is not a complete agreement on this factor, with some authors dismissing its relevance because in some cases EC does not show a statistically significative correlation with Building Age [31].

The most commonly mentioned factor (see Table 13) within the articles selected is the utilization of Heating, Ventilation, and Air Conditioning Systems (HVAC). Their impact on energy use affects all kinds of buildings, accounting for up to 40% of their EC [87]. University buildings are no exception [88,89], with several articles reporting examples of HVAC being a significant determinant of EC in geographically dispersed HEIs [57,90,91] . As HVAC utilization is such a critical factor for EC, there is an important academic trend focused on studying potential reductions in the resources required by those systems, with authors proposing that their optimization is the most effective measure to reduce energy expenditure [29].

Lighting Systems are a common source of EC addressed in 39 of the 175 selected papers. It is a central factor driving energy use, and in some geographical areas is even as important as HVAC [92]. As such, Lighting Systems present opportunities to save energy, with retrofitting being a measure that can be used to increase efficiency. Automatic control systems also offer interesting opportunities, as in some cases considerable energy wastage occurs due to lights being left on outside of working hours [93].

5. Conclusions

An SLR focused on EC in HEIs was conducted for the period 2006-2022. It has proven a useful method for determining key characteristic of scientific papers, academic trends, and common consumption drivers. The SLR allowed us to extend locally-focused findings to a larger scale, and overall to close the research gaps. In this research, characteristics of EC studied in specific Universities, classified as behavioral, institutional and technical factors in addition to effects related to climate were demonstrated to be valid globally.

The analysis of the literature highlights the importance of HEIs becoming sustainable institutions, given their prominent position in society. They must embrace sustainability, demonstrate their commitment to eco-friendly policies and thus ask the University community to change their environmental behavior.

Major findings point to a technical bias in this research field, as Engineering and Energy are the leading disciplines among the selected papers, with a limited role played by Social Sciences. The USA, China and the UK are revealed as the main countries behind the scientific papers on this topic. Energy and Buildings is the preferred journal for publishing articles about this subject, while the University of Sheffield (albeit by a small margin) is the leading organization in this regard. In terms of authors, Zhonghua Gou is the most prolific, while Mehreen Gul and Sandhya Patidar are the most cited.

Based on the results obtained, we can conclude that although this topic has attained a moderate degree of multidisciplinarity, it has been achieved through a combination of exact sciences, without any significant inclusion of social sciences. Therefore, it would be advisable to carry out more original research including disciplines related to the social sciences in order to enhance the understanding of how students, scholars, and higher education workers' behavior impacts EC.

The analyzed papers identified 12 main factors determining EC in HEIs. These were i) HVAC, ii) Occupancy Factors, iii) Climate, iv) Building Function, v) Lighting Systems, vi) Occupant Behavior, vii) Electronic Devices, viii) Gross Floor Area, ix) Building Age, x) Research intensity/Discipline Orientation, xi) Building Design and xii)Building Envelope. These EC drivers are in line with those of other sectors, such as the residential sector. However, when focusing on EC in HEIs, Building Function, Research intensity and Discipline orientation were revealed as distinctive factors. This finding indicates that technically specialized institutions and research-oriented Universities are intense energy consumers, with laboratories having high EUI. As a consequence, a specific energy saving design for buildings in these kinds of institutions is recommended, along with the acquisition of energy efficient equipment. On the other hand, for teaching-oriented institutions, whose EC is determined by larger floor areas used by libraries and classrooms, a different energy saving design must be considered. The latter approach focuses on reducing energy consumed for heating and cooling.

Our findings were limited by the following constraints: i) only articles and conferences papers written in English were considered; ii) papers published before 2007 were not available in the WOS database; and iii) articles are not characterized individually within a discipline, but are automatically assigned that of the publishing source. Finally, given the rapid growth in scholarly output about this topic, a new SLR should be conducted in the near future, in order to compare these results with those from a larger set of articles.

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Appendix A Examples of articles researching EC in a specific institution or country

Table A1. Examples of articles researching EC in a specific institution or country.

REFERENCE	COUNTRY	University	Findings
[94]	Ecuador	Escuela Politécnica del Litoral	Analysis of electrical loads indicated that most of the electricity is used by both air conditioning equipment and lighting (65%).
[95]	Greece	Democritus University of Trace	The energy intake of education buildings represents an important amount of the country's total energy demand. This due to the large amount of educational buildings in the country, forcing the state to incur considerable costs for the operation and maintenance of those premises
[41]	Mexico	National Autonomous University of Mexico	Analyzed the energy demand at the main campus of National Autonomous University of Mexico (130,000 Students), which consumed 81,3 GWH of electricity in 2011 (11 million USD)
[96]	Turkey	Balikesir University	The Balikesir University presents potential for energy savings of 60% in the analyzed buildings
[60]	USA	University of Michigan	Staff are most concerned about conserving energy in University buildings while students are the least concerned.

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Appendix B The reviewed studies on EC in Universities

Table A2. The reviewed studies on EC in Universities.

ID	Title	Doc Type	Source	Author
1	A comparative study of approaches towards energy efficiency and renewable energy use at higher education institutions	Article	WOS_CORE/SCOPUS	[97]
2	A comparative study on electrical energy usage of University residences in South Africa	Conference Paper	SCOPUS	[68]
3	A Heuristic-Based Smart HVAC Energy Management Scheme for University Buildings	Article	WOS_CORE/SCOPUS	[14]
4	A methodology to estimate baseline energy use and quantify savings in electrical energy consumption in higher education institution buildings: Case study, Federal University of Itajubá (UNIFEI)	Article	WOS_CORE/SCOPUS	[98]
5	A modelling applied to active renewable energy for an existing building of higher educational institution	Article	WOS_CORE/SCOPUS	[99]
6	A new Generation of Thermal Energy Benchmarks for University Buildings	Article	WOS_CORE/SCOPUS	[100]
7	A Preliminary assessment of energy consumption behaviour pattern and factors influence among Malaysian higher education institutions students	Article	SCOPUS	[62]
8	A review on Energy Performance in Malaysian Universities Through Building Information Modelling (BIM) Adaptation	Conference Paper	SCOPUS	[56]
9	A Roadmap for climate action at the University of Calgary: higher education campuses as climate leaders	Article	WOS_CORE/SCOPUS	[101]
10	A Study on the energy conservation policy of South Korean Universities	Conference Paper	SCOPUS	[102]
11	A Study on the energy performance of school buildings in Taiwan	Article	WOS_CORE/SCOPUS	[77]
12	A Study on the energy-saving potential of University campuses in Turkey	Article	WOS_CORE/SCOPUS	[96]
13	A summary of the research on building load forecasting model of colleges and Universities in North China based on energy consumption behaviour: A case in North China	Article	WOS_CORE/SCOPUS	[57]
14	A variation focused cluster analysis strategy to identify typical daily heating load profiles of higher education buildings	Article	WOS_CORE/SCOPUS	[33]
15	Actual building energy use patterns and their implications for predictive modelling	Article	WOS_CORE/SCOPUS	[79]
16	An Energy saving potential analysis of lighting retrofit scenarios in outdoor lighting systems: A case study for a University campus	Article	WOS_CORE/SCOPUS	[103]
17	An intelligent energy management system for educational buildings	Article	WOS_CORE/SCOPUS	[104]
18	Analysis of energy consumption structure of a science and engineering University campus in Southern China	Article	SCOPUS	[105]
19	Analysis of energy data of existing buildings in a University Campus	Article	WOS_CORE/SCOPUS	[86]
20	Analysis of energy performance of University campus buildings using statistical and energy modelling approaches	Conference Paper	SCOPUS	[106]
21	Analysis of energy use intensity and greenhouse gas emissions for Universities in Taiwan	Article	WOS_CORE/SCOPUS	[5]
22	Analysis of the energy usage in University buildings: The case of Aristotle University campus	Conference Paper	SCOPUS	[65]
23	Analysis of University science facilities energy consumption	Article	SCOPUS	[107]
24	Analysis on Energy Consumption and Energy-Saving Retrofit of University Buildings in Hot Summer and Cold Winter Zone of China	Conference Paper	SCOPUS	[88]
25	Application of an energy management and control system to assess the potential of different control strategies in HVAC systems	Article	WOS_CORE/SCOPUS	[29]
26	Application of international energy efficiency standards for energy auditing in a University buildings	Article	WOS_CORE/SCOPUS	[108]

27	Application of smart electronic systems, firm characteristics and efficient energy Consumption – a case of public Universities in Uganda	Article	WOS_CORE/SCOPUS	[109]
28	Application study of green building technology in Universities and colleges in cold regions	Conference Paper	SCOPUS	[81]
29	Applications of occupancy and booking information to optimize space and energy use in higher education institutions	Conference Paper	SCOPUS	[4]
30	Assessing the impact of the COVID-19 lockdown on the energy Consumption of University buildings	Article	WOS_CORE/SCOPUS	[110]
31	Assessing the nearly zero-energy building gap in University campuses with a feature extraction methodology applied to a case study in Spain	Article	WOS_CORE/SCOPUS	[111]
32	Assessing unregulated electricity Consumption in a case study University	Article	WOS_CORE/SCOPUS	[112]
33	Assessment of Energy Wastage and Saving Potentials for Higher Educational Institutional Buildings in South Western Nigeria	Conference Paper	SCOPUS	[82]
34	Assessment of the potential savings resulting from shutting down University buildings during periods of very low occupancy: A case study	Conference Paper	SCOPUS	[113]
35	Benchmark analysis of electricity consumption for complex campus buildings in China	Article	WOS_CORE/SCOPUS	[114]
36	Benchmarking Energy Use at University of Almeria (Spain)	Article	WOS_CORE/SCOPUS	[115]
37	Bridging the gap between energy and comfort: Post-occupancy evaluation of two higher-education buildings in Sheffield	Article	WOS_CORE/SCOPUS	[116]
38	Building energy consumption in the Universities of China: Situation and countermeasures	Conference Paper	SCOPUS	[117]
39	Building energy use prediction owing to climate change: A case study of a University campus	Conference Paper	SCOPUS	[118]
40	Building simulation tools and their role in improving existing building designs	Conference Paper	SCOPUS	[119]
41	Carbon-Neutral-Campus Building: Design Versus Retrofitting of Two University Zero Energy Buildings in Europe and in the United States	Article	WOS_CORE/SCOPUS	[120]
42	Case study for energy efficiency measures of buildings on an urban scale	Conference Paper	SCOPUS	[121]
43	Challenges in load profile monitoring: Case study	Conference Paper	SCOPUS	[80]
44	Cluster analysis of University campus smart meter data	Conference Paper	SCOPUS	[122]
45	Comparative studies of the occupants' behaviour in a University building during winter and summer time	Article	SCOPUS	[123]
46	Comprehending the energy consumption pattern of occupancy of an academic structure	Conference Paper	SCOPUS	[124]
47	COVID-19 Pandemic Effect on Energy Consumption in State Universities: Michoacan, Mexico Case Stud y	Article	WOS_CORE/SCOPUS	[125]
48	Data Analysis on building load profiles: A stepping stone to future campus	Conference Paper	SCOPUS	[126]
49	Decarbonising Universities: Case Study of the University of Exeter's Green Strategy Plans Based on Analysing Its Energy Demand in 2012-2020	Article	WOS_CORE/SCOPUS	[127]
50	Decision Support System in Establishing Energy Management System for the Engineering Building of Bulacan State University	Conference Paper	SCOPUS	[91]
51	Determination of territorial compactness and analysis of optimization of energy-efficient characteristics of the University campus	Conference Paper	SCOPUS	[128]
52	Determining key drivers of efficient electricity management practices in public Universities in Southwestern Nigeria An empirical study	Article	WOS_CORE/SCOPUS	[55]
53	Development of a web based energy management system for University Campuses: The CAMP-IT platform	Article	WOS_CORE/SCOPUS	[34]
54	Development of green campus in China	Article	WOS_CORE/SCOPUS	[30]

55	Diagnosis and reduction of electricity consumption exceedance in public University buildings	Article	SCOPUS	[76]
56	Distributed Energy Optimization for HVAC Systems in University Campus Buildings	Article	WOS_CORE/SCOPUS	[89]
57	Dual assessment Framework to Evaluate LEED-Certified Facilities Occupant Satisfaction and Energy Performance: Macro and Micro Approaches	Conference Paper	SCOPUS	[129]
58	Effect evaluation of introduced building energy management system in University campus	Conference Paper	SCOPUS	[7]
59	Effectiveness of daylighting design and occupant visual satisfaction in a LEED Gold laboratory building	Article	WOS_CORE/SCOPUS	[32]
60	Effects of occupant behaviour on energy performance in buildings: a green and non-green building comparison	Article	WOS_CORE/SCOPUS	[58]
61	Efficient energy modelling of heterogeneous building portfolios	Article	WOS_CORE/SCOPUS	[84]
62	Electrical Consumption in the Higher Education sector, during the COVID-19 shutdown	Conference Paper	SCOPUS	[15]
63	Electricity conservation opportunities within private University campuses in Bangladesh	Article	WOS_CORE/SCOPUS	[130]
64	Encouraging pro-environmental behaviour: Energy use and recycling at Rhodes University, South Africa	Article	WOS_CORE/SCOPUS	[131]
65	Energy and environmental performance of a higher education sector – a case study in the United Kingdom	Article	WOS_CORE/SCOPUS	[132]
66	Energy audit and multi-criteria decision analysis to identify sustainable strategies in the University campuses: Application to politecnico di Torino	Conference Paper	SCOPUS	[11]
67	Energy challenges: isolating results due to behaviour change	Article	WOS_CORE/SCOPUS	[8]
68	Energy conservation attitudes, knowledge, and behaviours in science laboratories	Article	WOS_CORE/SCOPUS	[71]
69	Energy conservation in China's higher education institutions	Article	WOS_CORE/SCOPUS	[75]
70	Energy Consumption Analysis of Education Buildings: The Case Study of Balikesir University	Article	WOS_CORE/SCOPUS	[133]
71	Energy consumption and GHG emission scenarios of a University campus in Mexico	Article	WOS_CORE/SCOPUS	[41]
72	Energy Consumption and the Power Saving Potential of a University in Korea: Using a Field Survey	Article	WOS_CORE/SCOPUS	[6]
73	Energy consumption pattern analysis by University building characteristics for the composition of green campus in Korea	Article	SCOPUS	[134]
74	Energy Consumption, Pandemic Period and Online Academic Education: Case Studies in Romanian Universities	Conference Paper	SCOPUS	[3]
75	Energy cost saving potential in educational buildings-case study of MUT campus	Conference Paper	SCOPUS	[135]
76	Energy efficiency actions at a Brazilian University and their contribution to sustainable development Goal 7	Article	WOS_CORE/SCOPUS	[136]
77	Energy efficiency analysis and energy conservation measures for Ethiopian Universities: Introducing green campus initiative	Conference Paper	SCOPUS	[137]
78	Energy efficiency analysis carried out by installing district heating on a University campus. A case study in Spain	Article	WOS_CORE/SCOPUS	[138]
79	Energy efficiency analysis in buildings of a University campus using the procel RTQ-C	Conference Paper	SCOPUS	[92]
80	Energy Efficiency and Distributed Generation: A Case Study Applied in Public Institutions of Higher Education	Article	WOS_CORE/SCOPUS	[139]
81	Energy Efficiency in School Buildings: The Need for a Tailor-Made Business Model	Conference Paper	SCOPUS	[140]
82	Energy efficiency index by considering number of occupants: A study on the lecture rooms in a University building	Article	SCOPUS	[141]
83	Energy efficiency interventions in UK higher education institutions	Article	WOS_CORE/SCOPUS	[48]
84	Energy efficiency measurements in a Malaysian public University	Conference Paper	SCOPUS	[142]
85	Energy efficiency of higher education buildings: a case study	Article	WOS_CORE/SCOPUS	[9]

86	Energy efficient management application in University buildings: Case of Malaysia public University	Article	SCOPUS	[143]
87	Energy management in the buildings of a University campus in Saudi Arabia - A case study	Conference Paper	SCOPUS	[144]
88	Energy Performance and Benchmarking for University Classrooms in Hot and Humid Climates	Article	WOS_CORE/SCOPUS	[145]
89	Energy performance evaluation of campus facilities	Conference Paper	SCOPUS	[146]
90	Energy performance of campus Leed buildings: Implications for green building and energy policy	Article	WOS_CORE/SCOPUS	[147]
91	Energy planning of University campus building complex: Energy usage and coincidental analysis of individual buildings with a case study	Article	WOS_CORE/SCOPUS	[64]
92	Energy refurbishment of a University building in cold Italian backcountry. Part 1: Audit and calibration of the numerical model	Conference Paper	SCOPUS	[148]
93	Energy refurbishment of a University building in cold Italian backcountry. Part 2: Sensitivity studies and optimization	Conference Paper	SCOPUS	[149]
94	Energy Saving Measures and Potential of Energy Efficiency at the University of Surabaya, Based on EDGE Simulation	Conference Paper	SCOPUS	[150]
95	Energy saving measures for University public library: A case study of UTHM library	Conference Paper	SCOPUS	[151]
96	Energy saving on campus: a comparison of students attitudes and reported behaviours in the UK and Portugal	Article	WOS_CORE/SCOPUS	[35]
97	Energy Savings Due to Daylight Saving in Mexico; Case Study: Buildings and Facilities of CU-UNAM	Conference Paper	SCOPUS	[152]
98	Energy use characteristics and benchmarking for higher education buildings	Article	WOS_CORE/SCOPUS	[31]
99	Enhancing the accountability and comparability of different campuses' energy profiles through an energy cluster approach	Article	WOS_CORE/SCOPUS	[73]
100	Estimating energy consumption and conservation measures for ESPOL Campus main building model using Energy Plus	Conference Paper	SCOPUS	[94]
101	Estimating potential saving with energy consumption behaviour model in higher education institutions	Article	SCOPUS	[153]
102	Estimation of Energy Savings Potential in Higher Education Buildings Supported by Energy Performance Benchmarking: A Case Study	Article	WOS_CORE/SCOPUS	[154]
103	Evaluation of environmental design strategies for University buildings	Article	WOS_CORE/SCOPUS	[155]
104	Examining the effect of an environmental social marketing intervention among University employees	Article	WOS_CORE/SCOPUS	[54]
105	Explorative Multidimensional Analysis for Energy Efficiency: DataViz versus Clustering Algorithms	Article	WOS_CORE/SCOPUS	[156]
106	Fostering the energy efficiency through the energy savings: The case of the University of Palermo	Conference Paper	SCOPUS	[157]
107	Green BIM-based study on the green performance of University buildings in northern China	Article	WOS_CORE/SCOPUS	[51]
108	How to improve eco-efficiency and indoor comfort at University of passo fundo - Brazil	Conference Paper	SCOPUS	[10]
109	Identifying the determinants of energy use in Texas A&M University campus at Kingsville	Conference Paper	SCOPUS	[158]
110	Impact of occupancy rates on the building electricity consumption in commercial buildings	Article	WOS_CORE/SCOPUS	[63]
111	Impact of the COVID-19 Pandemic on the Energy Use at the University of Almeria (Spain)	Article	WOS_CORE/SCOPUS	[159]
112	Incorporating machine learning with building network analysis to predict multi-building energy use	Article	WOS_CORE/SCOPUS	[160]
113	Influence of building and indoor environmental parameters on designing energy efficient buildings	Article	WOS_CORE/SCOPUS	[83]
114	Influence of occupants' behaviour on energy and carbon emission reduction in a higher education building in the UK	Article	SCOPUS	[161]
115	Internal benchmarking of higher education buildings using the floor-area percentages of different space usages	Article	WOS_CORE/SCOPUS	[162]

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116	Inter-University Sustainability Benchmarking for Canadian Higher Education Institutions: Water, Energy, and Carbon Flows for Technical-Level Decision-Making	Article	WOS_CORE/SCOPUS	[74]
117	Living Building Laboratory - Educational Building Project in Cluj-Napoca	Conference Paper	SCOPUS	[163]
118	Management strategies for sustainability education, planning, design, energy conservation in California higher education	Article	WOS_CORE/SCOPUS	[53]
119	Methodology for estimating energy and water Consumption patterns in University buildings: case study, Federal University of Roraima (UFRR)	Article	WOS_CORE/SCOPUS	[2]
120	Methodology of measurement and calculation of building energy management system in University campus	Conference Paper	SCOPUS	[164]
121	Modelling energy Consumption behaviour using "energy culture" concept for student accommodations in Malaysian public Universities	Article	WOS_CORE/SCOPUS	[61]
122	Modelling energy demand from higher education institutions: A case study of the UK	Article	WOS_CORE/SCOPUS	[13]
123	Multi-agent system for energy consumption optimisation in higher education institutions	Article	WOS_CORE/SCOPUS	[165]
124	Non-domestic energy use - Experiences of the Higher Education sector	Conference Paper	SCOPUS	[66]
125	Occupancy diversity factors for common University building types	Article	WOS_CORE/SCOPUS	[28]
126	Occupant thermal feedback for improved efficiency in University buildings	Article	WOS_CORE/SCOPUS	[90]
127	Optimization of the management of building stocks: An example of the application of managing heating systems in University buildings in Spain	Article	WOS_CORE/SCOPUS	[166]
128	Optimizing the energy efficiency of higher education institutions	Conference Paper	SCOPUS	[167]
129	Parametric studies on European 20-20-20 energy policy targets in University environment	Article	WOS_CORE/SCOPUS	[168]
130	Potential opportunities for energy conservation in existing buildings on University campus: A field survey in Korea	Article	WOS_CORE/SCOPUS	[27]
131	Potential reduction of energy consumption in public University library	Conference Paper	SCOPUS	[169]
132	Prevalence of Findings from ASHRAE Level 2 Energy Assessments at 13 Colleges	Article	SCOPUS	[1]
133	Prioritizing Energy-efficiency and Renewable-energy Measures in a Low-carbon Campus using Analytic Hierarchy Process with Social Awareness Criterion	Article	WOS	[21]
134	Quantifying potential savings from sustainable energy projects at a large public University: An energy efficiency assessment for Texas state University	Article	WOS_CORE/SCOPUS	[170]
135	Quantity and electricity consumption of plug load equipment on a University campus	Article	WOS_CORE/SCOPUS	[72]
136	Recommending a thermal energy benchmark based on CIBSE TM46 for typical college buildings and creating monthly energy models	Article	WOS_CORE/SCOPUS	[171]
137	Reducing University energy use beyond energy retrofitting: The academic calendar impacts	Article	WOS_CORE/SCOPUS	[70]
138	Reflection upon energy saving and emission reduction in colleges in the context of low carbon city construction	Conference Paper	SCOPUS	[172]
139	Regression Model-Based Short-Term Load Forecasting for University Campus Load	Article	WOS_CORE/SCOPUS	[78]
140	Research on Construction Strategy of Energy Conservation and Emission Reduction in University Campuses in Beijing	Conference Paper	SCOPUS	[173]
141	Research on saving energy and reducing cost of the higher learning institution	Conference Paper	SCOPUS	[174]
142	Research on the building energy efficiency design strategy of Chinese Universities based on green performance analysis	Article	WOS_CORE/SCOPUS	[52]
143	Retrofit of educational facility through passive strategies in hot climate	Conference Paper	SCOPUS	[175]

144	Review of the research on energy consumption evaluation index system of campus	Article	SCOPUS	[176]
145	Sector review of UK higher education energy consumption	Article	WOS_CORE/SCOPUS	[39]
146	Significant factors of energy consumption behaviour pattern among Malaysian Higher Education Institutions students	Conference Paper	SCOPUS	[177]
147	Status and countermeasures of energy management in Chinas college	Conference Paper	SCOPUS	[178]
148	Strategies for a sustainable campus in Osaka University	Article	WOS_CORE/SCOPUS	[179]
149	Student Housing Energy Consumption: A Comparison of Chilled Water, Heating, and Electricity Use	Conference Paper	SCOPUS	[180]
150	Study of electricity load profiles in University Campuses: The case study of democritus University of thrace	Conference Paper	SCOPUS	[93]
151	Study on energy consumption quotas development method of colleges and Universities in Hubei	Conference Paper	SCOPUS	[181]
152	Survey of energy consumption and energy conservation measures for colleges and Universities in Guangdong province	Article	WOS_CORE/SCOPUS	[40]
153	Survey on energy consumption and indoor thermal environment of University Building in Changsha, China	Conference Paper	SCOPUS	[182]
154	Sustainability and natural resources uses at a South Brazilian University: Proposing an environmental plan to University of Passo Fundo	Conference Paper	SCOPUS	[183]
155	Sustainability in University campus: options for achieving nearly zero energy goals	Article	WOS_CORE/SCOPUS	[184]
156	Sustainable and smart University Campuses; Strategic approach to sustainability and building intelligence for University Campuses	Conference Paper	SCOPUS	[185]
157	Sustainable Campus: The Experience of the University of Lisbon at IST	Article	WOS_CORE/SCOPUS	[186]
158	Sustainable management of existing building stock: A strategy to reduce the energy consumption and the environmental impact	Conference Paper	SCOPUS	[187]
159	The energy planning according to the ISO 50001 contribute to the consolidation of a Sustainable Campus to the Universidad Autónoma de Occidente	Conference Paper	SCOPUS	[188]
160	The human dimension of energy conservation and sustainability. A case study of the University of Michigan energy conservation program	Article	WOS_CORE/SCOPUS	[60]
161	The impact of Climate Change on a University Campus' Energy Use: Use of Machine Learning and Building Characteristics	Article	SCOPUS	[85]
162	The impact of COVID-19 on higher education building energy use and implications for future education building energy studies	Article	WOS_CORE/SCOPUS	[189]
163	The motivation and development impact of energy saving to sustainability in the construction of green campus: a case study of the Zhejiang University, China	Article	WOS_CORE/SCOPUS	[190]
164	The Potential Role of Stakeholders in the Energy Efficiency of Higher Education	Article	WOS_CORE/SCOPUS	[191]
165	The relationship between energy use and space use of higher educational buildings in subtropical Australia	Article	WOS_CORE/SCOPUS	[69]
166	The successful introduction of energy efficiency in higher education institution buildings	Conference Paper	SCOPUS	[87]
167	Towards energy transition at the Faculty of Education of Bilbao (UPV/EHU): diagnosing community and building	Article	WOS_CORE/SCOPUS	[192]
168	Transformation of a University building into a zero energy building in Mediterranean climate	Article	WOS_CORE/SCOPUS	[95]
169	Understanding Campus Energy Consumption - People, Buildings and Technology	Conference Paper	SCOPUS	[193]
170	Understanding the energy consumption and occupancy of a multi-purpose academic building.	Article	WOS_CORE/SCOPUS	[26]
171	University building: Energy diagnosis and refurbishment design with cost-optimal approach. Discussion about the effect of numerical modelling assumptions	Article	WOS_CORE/SCOPUS	[194]

172	University campuses energy performance estimation in Ukraine based on measurable approach	Article	WOS_CORE/SCOPUS	[195]
173	Use of electrical energy in University buildings: a Hong Kong case study	Article	SCOPUS	[67]
174	Using energy profiles to identify University energy reduction opportunities	Article	WOS_CORE/SCOPUS	[196]
175	Workflow automation for combined modelling of buildings and district energy systems	Article	WOS_CORE/SCOPUS	[197]

Appendix C Subject Areas Overlaps Matrix.

Table A3. Subject Areas Overlaps Matrix.

	Agricultural and Biological Scienc	Arts and Humanities	Business, Management and Acco	Chemical Engineering	Computer Science	Decision Sciences	Earth and Planetary Sciences	Economics, Econometrics and Fin	Energy	Engineering	Environmental Science	Material Science	Mathematics	Medicine	Multidisciplinary	Physics and Astronomy	Social Sciences	**Total Overlaps**
Agricultural and Biological Sciences		0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	**2**
Arts and Humanities	0		0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	**3**
Business, Management and Accounting	0	0		0	0	1	0	0	6	8	6	0	0	0	0	0	0	**21**
Chemical Engineering	0	0	0		2	0	0	0	4	2	0	0	2	0	0	0	0	**10**
Computer Science	0	0	0	2		6	0	0	7	17	3	2	9	0	0	2	2	**50**
Decision Sciences	0	0	1	0	6		0	0	1	3	1	0	2	0	0	1	1	**16**
Earth and Planetary Sciences	0	0	0	0	0	0		0	3	0	6	0	0	0	0	0	0	**9**
Economics, Econometrics and Finance	0	0	0	0	0	0	0		0	0	1	0	0	0	0	0	2	**3**
Energy	1	0	6	4	7	1	3	0		29	28	0	12	0	0	2	12	**105**
Engineering	0	2	8	2	17	3	0	0	29		15	3	16	2	1	3	10	**111**
Environmental Science	1	0	6	0	3	1	6	1	28	15		0	2	2	0	0	12	**77**
Material Science	0	0	0	0	2	0	0	0	0	3	0		0	0	0	0	0	**5**
Mathematics	0	0	0	2	9	2	0	0	12	16	2	0		0	0	3	0	**46**
Medicine	0	0	0	0	0	0	0	0	0	2	2	0	0		0	0	2	**6**
Multidisciplinary	0	0	0	0	0	0	0	0	0	1	0	0	0	0		0	0	**1**
Physics and Astronomy	0	0	0	0	2	1	0	0	2	3	0	0	3	0	0		0	**11**
Social Sciences	0	1	0	0	2	1	0	2	12	10	12	0	0	2	0	0		**42**
Total Overlaps	**2**	**3**	**21**	**10**	**50**	**16**	**9**	**3**	**105**	**111**	**77**	**5**	**46**	**6**	**1**	**11**	**42**	**518**

Source: own elaboration based on data extracted from Scopus on 4-27-2022

Appendix D International Collaboration Matrix (174 Scopus Articles)[11]

Table A4. International Collaboration Matrix.

Collaborative Articles	Australia	Belgium	Brazil	Canada	China	Colombia	Ecuador	Ethiopia	Germany	Greece	Hong Kong	India	Indonesia	Iran	Ireland	Italy	Japan	Kyrgyzstan	Latvia	Lebanon	Malaysia	Morocco	Netherlands	New Zealand	Nigeria	Norway	Pakistan	Portugal	Romania	Russian Federation	Saudi Arabia	South Africa	Spain	Switzerland	United Arab Emirates	United Kingdom	United States	**Total Links**
Australia		0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	**5**
Belgium	0		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Brazil	0	1		0	0	1	0	0	1	0	1	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	3	0	1	0	0	1	0	0	1	0	**14**
Canada	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	**2**
China	2	0	0	0		0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	**7**
Colombia	0	0	1	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Ecuador	0	0	0	0	0	0		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Ethiopia	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Germany	0	0	1	0	0	0	0	0		0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	**7**
Greece	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	**3**
Hong Kong	1	0	1	0	1	0	0	0	1	0		0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	**10**
India	0	0	1	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	**3**
Indonesia	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Iran	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**4**
Ireland	0	0	0	0	0	0	0	0	0	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Italy	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0		0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	**7**
Japan	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Kyrgyzstan	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0		0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	**6**
Latvia	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Lebanon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Malaysia	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0		0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	**7**
Morocco	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	**1**
Netherlands	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	1	0	0	0	**3**
New Zealand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	1	0	0	0	0	**1**
Nigeria	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1	0	0	0	0	0	**3**
Norway	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	**2**
Pakistan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	1	0	**1**
Portugal	0	0	3	0	0	0	0	0	1	1	1	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0		0	1	0	0	0	0	0	1	0	**12**
Romania	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	**1**
Russian Federation	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		0	0	0	0	0	0	0	**3**
Saudi Arabia	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	2	0	**3**
South Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		0	0	0	0	1	**2**
Spain	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0		0	0	1	0	**4**
Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0		0	0	0	**3**
United Arab Emirates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	**1**
United Kingdom	1	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	2	0	1	0	0		1	**13**
United States	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1		**8**
Total Links	**5**	**2**	**14**	**2**	**7**	**1**	**1**	**1**	**7**	**3**	**10**	**3**	**1**	**4**	**1**	**7**	**2**	**6**	**2**	**1**	**7**	**1**	**3**	**1**	**3**	**2**	**1**	**12**	**1**	**3**	**3**	**2**	**4**	**3**	**1**	**13**	**8**	**148**

Source: own elaboration based on data extracted from WOS and Scopus on 4-27-2022
Only countries with more than one link

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