



Education Of Carbon Footprint And Energy Efficiency In Higher Education: Insights From A Bibliometric

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Abstract. CO₂ emissions are reduced by cutting fossil energy use. Matters on carbon emission efficiency or low carbon education can be delivered through educational processes. This study aims to describe articles in terms of total publications, citations, authors, countries, journals, publishers, and co-authorship network using most frequently used keywords and determine what is to be researched in the future. Bibliometrics was used to review articles in the Scopus database (2003–2023). The PRISMA model was used for data collection, and VOSviewer and Harzing's Publish or Perish were employed for data analysis. A total of 917 articles were identified, and 456 were selected. The results of the study showed that there has been an increase in the number of publications. Most of the studies were conducted in China, the USA, and the UK. Journal of Cleaner Production and Elsevier Ltd have been the most productive journal and publisher. The most frequently used keywords in research was "carbon". Within the period, several keywords such as "low carbon", "higher education", and "education" have been unrelated and understudied. It was found that the "low-carbon" policy has been implemented in the forms of energy policy, engineering education, and energy efficiency. Monitoring of "carbon emissions" has been conducted in the form of carbon footprint, strengthened by controls such as controls of "energy use", "energy efficiency", "energy consumption", and "carbon footprint". "Emissions control" needs to be linked with "education". Based on the findings, further studies on "energy efficiency" and "carbon footprint" combined with "education" are needed.

Keywords: Low Carbon; Bibliometrics; Energy Efficiency; Carbon Footprint; Scopus.

1. Introduction

The International Panel on Climate Change (IPCC) reported that human activities using fossil energy have a significant impact on climate change (1). Energy use includes both private (e.g., household energy, private vehicles, aviation, and public transportation) and non-personal (e.g., commercial, industrial, and freight facilities) purposes (2). The main

activity that impacts climate change is the industrial one. Growing industrialization has increased energy demand. As much as 58% of Indonesia's electrical energy needs are supplied by coal-fired power plants (3). Using coal fuel in power plants will increase carbon dioxide emissions (4).

From 1990 to 2019, CO₂ gas emissions from industry have increased significantly by 64% (<https://news.un.org/en/story/2022/04/1115452>). The increase in CO₂ emissions impacts the excessive build-up of greenhouse gases in the atmospheric layer. The build-up of this gas leads to the formation of a thin layer of CO₂ gas which has the effect of trapping some of the heat from sunlight on the earth. This causes an increase in the global average temperature (1).

The rise in global temperature has caused climate instability, known as climate change. The IPCC warned that before 2030, the average global temperature rise should not exceed 1.5 °C. An increase in global temperature of more than 1.5 °C will have an extreme impact on human life. The global temperature is predicted to increase from 2030 to 2050, which urges curbing efforts (1). The global temperature rise can cause health problems, such as dehydration, loss of kidney function, skin diseases, infections in the tropics, mental health problems, pregnancy complications, and allergies (5). In addition, climate change also drives a decline in soil quality and agricultural products, affecting the adequacy of nutritional sources for humans (6). To address this condition, a solution in the form of carbon (CO₂) emissions reductions is needed.

In response to climate change, many scientists have taken action to reduce greenhouse gas emissions. The United Nations Conference on Environment and Development in Rio de Janeiro in June 1992 adopted the term 'Framework Convention on Climate Change'. This is a global agreement to deal with changes in global warming. In 2003, the concept of "low carbon" was first introduced in UK energy under the title "Our Energy Future: Creating a Low Carbon Economy" (7). The concept of "low carbon" has been developed in various fields, such as economics, architecture, energy, and even education.

Solutions to the problem of global temperature rise include mitigation and adaptation actions to climate change (8). Understanding mitigation and adaptation is a step towards increasing insight into climate change. Adaptation activities focus on adjusting to the various changes due to climate change. Meanwhile, mitigation focuses on reducing the sources that cause global warming, namely CO₂ emissions. Carbon emissions can be reduced by streamlining the use of fossil-sourced energy in all human activities.

According to Chatterton, there are two main groups of energy consumption behaviour models: individualist and socially oriented (9). The individualist model includes energy saving and emissions reductions, while the socially oriented model includes the provision of infrastructure, management systems, and green technology. To control the increasing

CO₂ emissions, education should be provided to all individuals. This is part of climate change mitigation activities.

Climate change education can be provided through formal or informal education, commonly called low carbon education (10). Low carbon education should include the concept of global warming and climate change. This is because low-carbon activities can reduce CO₂ emissions, thereby reducing global warming. There have been several studies that focus on climate change mitigation and adaptation. Studies on low carbon have also been carried out. To see the extent to which the studies have been carried out, it is necessary to conduct a literature review.

Bibliometric research is a literature review method used to find trends in a topic. There have been some bibliometric studies on "low carbon," including one by Hudha & Permasari (2020) and another by X. Wang, Wang, Chen, Zeng, & Kiang (2022) (listed in Table 1). The first article examines how the trend of "low carbon education" has developed since 2014 until 2020 using the Google Scholar database. The article also discusses the most productive publishers, journals, countries, and authors, as well as the development of article citations. The second article discusses the topic of a "low-carbon city" which does not involve education using the WoS database. Based on the article, data on the most productive countries, the most productive authors, and trends in more specific research themes such as low-carbon transition of energy, low-carbon decision tools, low-carbon planning and design, and low-carbon policy and management were obtained. From the articles, recommendations for future research are obtained.

Due to the limited databases used in the previous studies, it is necessary to conduct a bibliometric study on "low carbon" in education using credible databases such as Scopus (12). Follow-up studies are expected to fill the gap, so that new references are obtained for future studies. Therefore, the purpose of this research is to address the following questions:

1. How is the distribution of descriptive results (total publications, citations by year, authors, countries, journals, publishers, and co-authorship network) of articles published on low carbon education?
2. Which keywords are used most, what educational fields are most examined, and what is to be researched next in the context of low carbon education?

Table 1. Articles on Bibliometric Analyses of Low Carbon Studies

Author	Low Carbon Education: A Review and Bibliometric Analysis (2020)	Low-carbon City and Its Future Research Trends: A Bibliometric Analysis and Systematic Review
Domain/Search Strategy	Low carbon education	Low carbon OR zero carbon OR carbon neutral OR free carbon

		AND urban OR city OR civil OR metropolitan OR town OR Municipal
Data Source & Scope	Google Scholar (2014–2019)	Web of Science (2002–2022)
Total Documents Examined	55 articles	1,096 articles
Software used in Bibliometrics	PoP, VOSviewer, Zotero, Microsoft Excel, and gpsvisualizer.com	VOS-viewer and CiteSpace
Bibliometric Attributes Examined	The results of the analysis revealed that "low carbon education" research is still dominated by China and Malaysia. There is a need for increased international collaboration.	The analysis obtained data on the most productive countries, the most productive authors, and trends in research themes including low carbon transition of energy, low-carbon decision tools, low-carbon planning and design, and low-carbon policy and management.

2. Methods

This research examined literature to answer several research questions. The distribution and development of low carbon education were studied through published articles. The development of low carbon education in various countries was analysed to identify the dominant countries, the most productive publisher, the most active journal, the most productive researchers, the network between researchers, citations, and specific keywords used.

This study aims to determine trends, the distribution of researchers, and the networks. Selection was conducted based on the data obtained to create research recommendations. This study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. Figure 1 illustrates the process of identifying review sources and data analysis methodology.

Scopus was chosen as the database for searching and extracting scientific articles because it provides comprehensive reference sources (12). The authors extracted scientific articles on March 24, 2023, with the keywords "low carbon" and "education" in the titles, abstracts, and keywords of the articles. Articles not discussing how to implement low-carbon

activities were excluded. The research scope was limited to articles published in English between 2003 and 2023 based on the search field, time frame, source type, and document type to exclude irrelevant papers. Based on the initial search, 917 articles were obtained. The articles obtained were then selected further by reading the abstracts. The screening results obtained 456 articles for further analysis.

The data obtained were then processed with several methods to answer the research questions. The search results are presented in Research Information Systems (RIS) and Comma-Separated Values (CSV) formats. To obtain citation metrics, Harzing's Publish or Perish software was used. In addition, to visualise keywords, distribution of researchers, and networks, the VOSviewer software was used. The results of this study have implications for the enrichment and expansion of low carbon education research.

3. Results and Discussions

Data were obtained from the Scopus database. The research focused on bibliometrics involving research keywords. It also focused on research trends based on years of publication, total publications, citation metrics, publishers, journals, researchers, and researchers' network. The research aims at figuring out the most influential or productive countries, the most frequently used keywords, and the most frequently examined educational fields in the context of low carbon education as well as at determining what is to be researched next. The keywords, authors, and citations by country analysed were mapped using VOSviewer. The data analysis was divided according to research questions (RQs). In order to answer the research questions, total publications, citations by year, authors, countries, journals, publishers, and co-authorship network were examined.

Initial search results using the Scopus search engine in terms of total publications and citations by year

The initial search using the Scopus search engine yielded 917 articles and 19,022 citations (952.10 citations/year). Further selection was conducted by studying the abstracts, and 456 articles and 7,379 citations (343.06 citations/year) were obtained. The selection process from 2003 to 2023 yielded the same articles as when 2006 was counted as the earliest year of publication. In the years 2003–2005, there were no publications related to low carbon education. More information can be found in Table 2.

Table 2. Comparison Publication Metrics

Metric Data	Initial Search	Refined Search
Source	" <i>Low carbon education</i> "	" <i>Low carbon education</i> "
Publication year	2003–2023	2006–2023
Papers	917	456

Citations	19,022	7,379
Citations/Year	952.10	343.06
Citations/Paper	20.74	16.18
Authors/Paper	4.26	3.62
h_index	67	47
g_index	105	67
hl_norm	32	24
hl_annual	1.60	1.41

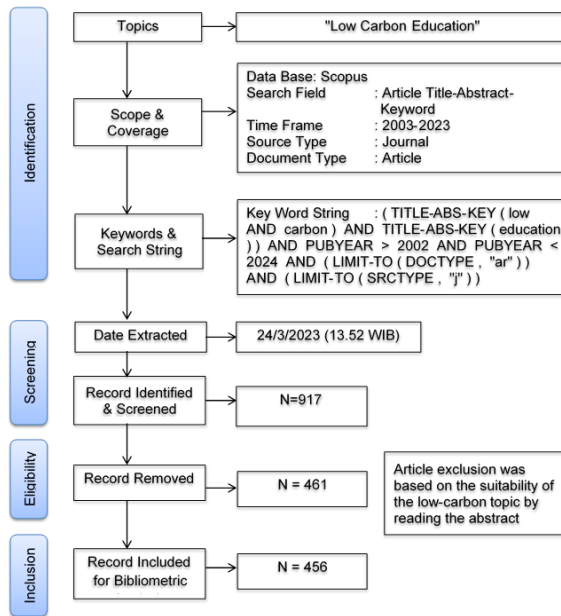


Fig 1. PRISMA Flow Diagram[13]

Based on the articles that have been selected (n = 456), as can be seen in Figure 2, the publication trend was that the number of documents increased from year to year. In the first three months of 2023 alone, there were 23 publications (see Table 3).

In contrast, the number of citations fluctuated. Throughout the entire period from 2006 to 2023, there were both increases and decreases in the number of publication citations. In 2008, 2012, 2016, 2018, and 2020–2022, the publication citations experienced significant declines. Particularly to 2023, the number of publication citations was low because data extraction was only conducted until March. On the other hand, the number of publication citations increased in 2011, 2013, 2014, 2017, and 2019. The highest number of publication citations was in 2017. It was estimated that in that year, the issue of low carbon education

peaked. From 2019 to 2023, the number of citations continued to decline, possibly due to the influence of the COVID-19 pandemic. The overall trend based on titles, abstracts, and keywords is presented in Figure 3.

Top 10 articles with the highest numbers of citations

Top ten articles with the highest number of citations of the 456 articles are described in Table 4. The article with the highest number of citations is entitled “Buildings Don't Use Energy: People Do”. This article discusses how to build buildings with efficient energy use. The design of the buildings, the equipment used, and the number of occupants in relation to energy efficiency and minimising CO2 emissions have been elusive and challenging to building designers before 2030[2].

The second subject for the proof process is observed from the point of view of things that usually occur in the process of mathematical proof. The results of the second subject's work can be observed in Figure 2.

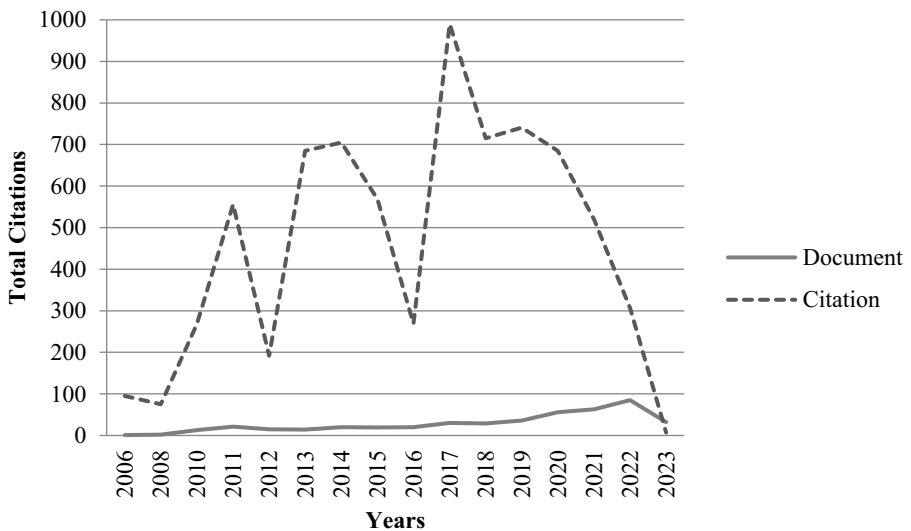


Fig 2. Total Publications and Citations by Year

Table 3. The Number of Low Carbon Education Research Publications by Year

Year	Documents	Citations	Number of cited publications
2006	1	95	1

2008	2	75	2
2010	13	268	11
2011	21	556	15
2012	15	192	14
2013	14	685	14
2014	20	705	20
2015	19	569	18
2016	20	269	18
2017	30	990	28
2018	29	715	29
2019	36	741	32
2020	56	685	49
2021	63	520	60
2022	85	307	50
2023	32	7	7
Total	456		

Article 1 aligns with articles 5, 7, and 8, all of which focus on implementing low carbon. The second and third articles discuss "carbon footprint". This topic is essential because it measures CO₂ emissions. It is necessary to identify how much CO₂ has been emitted from daily activities. This theme is shared with articles 9 and 10. Meanwhile, article 6 focuses on improving human resources in implementing low-carbon methods or policies.

Low-carbon education research ranking by country and how countries collaborate

How many document exist in low carbon education research? How do they collaborate? To answer these questions, we analysed the publication network of countries with the criteria of at least five documents per country and at least five citations per country using the VOSviewer software. From the analysis, 27 countries meeting the criteria were obtained (see Table 5).

Based on the bibliometric analysis, research on "low carbon education" is evenly distributed across the Americas, Europe, Asia, and Australia, except for Africa, with China, the USA, and the UK being predominant. This contradicts the research results of Hudha & Permasari (2020), which show that research on "low carbon education" is dominated by Asian countries, especially China and Malaysia. This deviation is presumably due to the use of different databases. This research used the Scopus database, while the research by Hudha & Permasari (2020) used the Google Scholar database. The present article can

strengthen the insights gained in previous research and help develop future "low carbon education" inquiries.

The network among countries in terms of "low carbon education" research based on article references or citations is visualised in Figure 3. The network opens up new opportunities for low carbon education research to be carried out in the future for better scientific sustainability, which is important for solving the problem of CO₂ emissions. Research on "low carbon education" continues to develop. Countries most recently conducting research in this field, including France, Malaysia, Italy, and Indonesia, are included in the visualisation in Figure 4.

Table 4. Top 10 Cited Articles

No	Year	Title	Journal	Cites	Publisher
1.	2011	Buildings Don't Use Energy: People Do	Architectural Science Review	252	Taylor & Francis
2.	2013	Carbon Footprints of Cities and Other Human Settlements in the UK	Environmental Research Letters	241	Institute of Physics Publishing
3.	2013	Who Emits Most? Associations between Socio-economic Factors and UK Households' Home Energy, Transport, Indirect, and Total CO ₂ Emissions	Ecological Economics	212	Elsevier Ltd
4.	2017	Urban Sustainability Assessment and Ranking of Cities	Computers, Environment, and Urban Systems	119	Elsevier Ltd
5.	2018	The Demographics of Decarbonizing Transport: The Influence of Gender, Education, Occupation, Age, and Household Size on Electric Mobility Preferences in the Nordic Region	Global Environmental Change	115	Elsevier Ltd

6.	2018	Trust, Awareness, And Independence: Insights from A Socio-psychological Factor Analysis of Citizen Knowledge and Participation in Community Energy Systems	Energy Research and Social Science	109	Elsevier Ltd
7.	2013	Decarbonising Road Transport with Hydrogen and Electricity: Long Term Global Technology Learning Scenarios	International Journal of Hydrogen Energy	104	Elsevier Ltd
8.	2012	Up-Scaling, Formative Phases, and Learning in the Historical Diffusion of Energy Technologies	Energy Policy	103	Elsevier Ltd
9.	2011	The New Urban Politics as a Politics of Carbon Control	Urban Studies	102	Sage Publications, Ltd
10.	2019	Exploring China's Carbon Emissions Peak for Different Carbon Tax Scenarios	Energy Policy	100	Elsevier Ltd

Table 5. Country Ranking Based on Documents

No	Country	Documents	Citations	Total Link Strength
1	China	173	2,573	57
2	United States	63	1,372	56
3	United Kingdom	65	2,250	45
4	Germany	17	638	28
5	Austria	10	188	23
6	Australia	24	759	22
7	Spain	17	177	20
8	Netherlands	12	447	19
9	Sweden	14	263	18
10	Italy	11	118	17

11	France	11	177	16
12	Denmark	7	267	12
13	Belgium	5	119	11
14	Poland	11	114	11
15	Japan	19	202	10
16	Pakistan	6	133	10
17	Switzerland	5	87	10
18	Norway	6	91	9
19	Portugal	5	56	9
20	Saudi Arabia	5	92	9
21	Finland	6	129	8
22	Malaysia	17	148	8
23	Canada	13	75	4
24	Indonesia	6	47	4
25	Ireland	6	53	2
26	South Korea	5	30	2
27	Taiwan	17	144	2

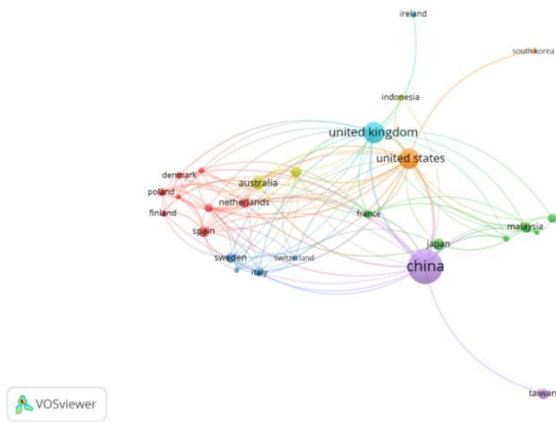


Fig 3. Network Visualisation Map of Citations by Country

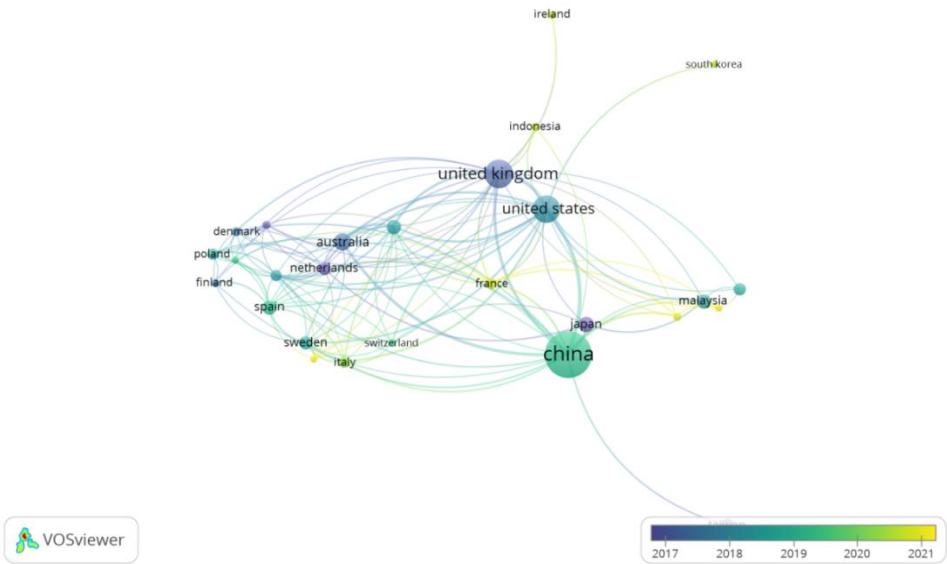


Fig 4. Country Overlay

Based on the analysis, the 456 articles were written by a total of 1,420 authors. To visualise the authorship network, the parameter of each author having at least three article documents was used. The visualisation generated is presented in Figure 5.

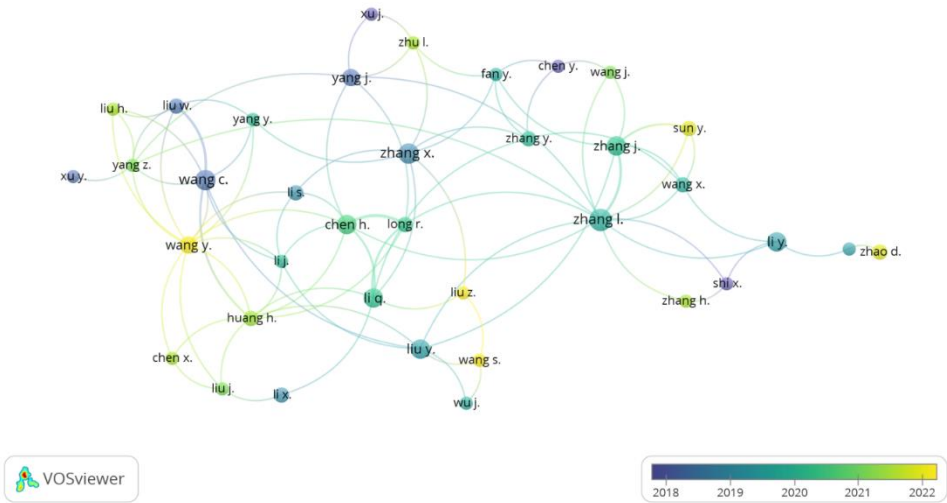


Fig 5. Network Visualization Map of Co-authorship

In general, the authors were dominated by researchers from China. The top three authors were Zhang I. (8 documents, 136 citations, and 14 networks), Chen H. (6 documents, 120 citations, and 12 networks), and Wang C. (7 documents, 187 citations, and 11 networks). In terms of journals, Table 6 presents journals which productively publish articles on "low carbon education". On average, productive journals have Quartile 1, except for the journal Buildings and Cities. Scopus has just indexed the journal. Although it has yet to have a quartile, it has already published many related articles.

The Most Productive Publishers in Low Carbon Education Research

Table 6. Ten Most Productive Journals

No	Journal	Articles	Quartile of JCR
1.	Journal of Cleaner Production	32	Q1
2.	Sustainability (Switzerland)	25	Q1
3.	Energy Policy	21	Q1
4.	Energies	14	Q1
5.	International Journal of Environmental Research and Public Health	11	Q1
6.	Environmental Science and Pollution Research	8	Q1
7.	Journal of Environmental Management	7	Q1
8.	Habitat International	6	Q1
9.	Energy Research and Social Science	6	Q1
10.	Buildings and Cities	6	Scopus (accepted and pending inclusion)

Elsevier Ltd is the most productive publisher in this study (Table 7). This aligns with previous research (10), although the previous study used a different database, Google Scholar.

Table 7. Ten Most Productive Publishers

No	Publisher	Articles
1.	Elsevier Ltd	145
2.	Springer	42
3.	MDPI	40
4.	Taylor and Francis Ltd.	16
5.	Routledge	16
6.	Frontiers Media S.A.	13

7.	Emerald Group Holdings Ltd.	10
8.	Academic Press	7
9.	John Wiley and Sons Inc	6
10.	American Chemical Society	5

Topic Analysis Using the Words in Each Article's Title, Abstract, and Keywords

The second research question (RQ 2) is “What are the main topics discussed in low-carbon education research?” Of the 456 validated articles, the topics were analysed using the words in each article's title, abstract, and keywords. Then, the topics were visualised using VOSviewer. The minimum parameter of "15 occurrences" was used in visualising the topics. The visualisation result takes the form of connected coloured dots. The line shows the relationship between keywords, the colour shows the research cluster, and the point size shows the number of studies with the topic of interest (Figure 6).

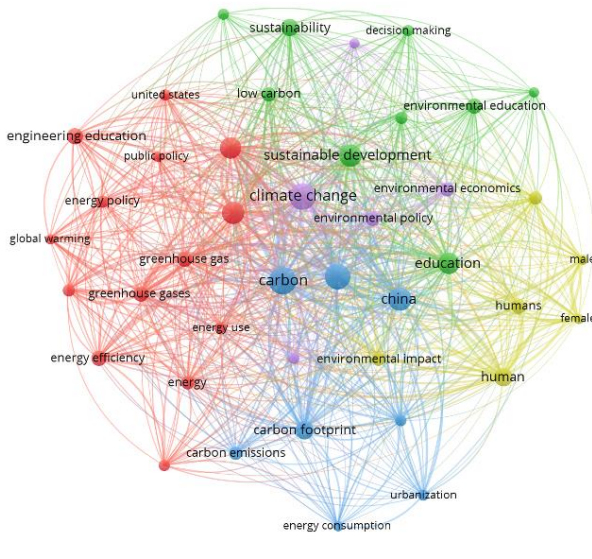


Fig 6. Network Visualisation Map of Keywords with at Least 15 Occurrences

The connected words were grouped into five clusters indicated by five colours: red, green, blue, yellow, and purple.

First cluster(red): carbon dioxide (1), emissions control (2), energy (3), energy efficiency (4), energy policy (5), energy use (6), energy utilization (7), energy consumption (8), gas emissions (9), global warming (10), greenhouse gas (11), greenhouse gases (12), public policy (13), United States (14)

Second cluster(green): decision making (15), environmental education (16), environmental management (17), higher education (18), low carbon (19), perception (20), sustainability (21), sustainability development (22)

Third cluster (blue): carbon (23), carbon emissions (24), carbon footprint (25), China (26), energy conservation (27), energy consumption (28), urbanization (29)

Fourth cluster(yellow): Environmental impact (30), environmental protection (32), female (33) human (34), humans (35), male (36)

Fifth Cluster(purple): carbon sequestration (37), climate change (38), environmental economics (39), environmental policy (40), mitigation (41)

The search using VOSviewer obtained a total of 3,955 keywords. After selection of keywords with a minimum of 15 occurrences, 51 keywords were obtained (selected again to 41). The keywords with the highest occurrences were “carbon” (110), with a comprehensive network of 582, “carbon emissions” (90), with a comprehensive network of 500, and “climate change” (97), with a comprehensive network of 422, as presented in Table 8.

Visualisation of research topic clustering

The resulting keyword clustering visualisation reflects how research topics were represented by keywords. Connected keywords show that the studies were interconnected in terms of citations. The closer the words are to each other, the more closely related the research topics (14).

It can also illustrate the novelty of research topics. As Figure 7 shows, this study includes relatively new research topics indicated by the yellow colour. By contrast, darker colours indicate that the topics have been researched for a long time.

In addition to the novelty of the topic, the research frequency can also be visualised. The 456 articles with a minimum of 15 occurrences are visualised in Figure 8. Topics in bright yellow indicate that they have been frequently raised in research, while darker colours indicate that the research is scarce. Some topics frequently researched are “China”, “climate change”, “emissions control”, “education”, “carbon footprint”, and “carbon”. Some others are understudied, including “low carbon”, “higher education”, “public policy”, “mitigation”, “urbanization”, “energy use”, “gas emissions”, and “energy”.

Low carbon education is a strategy to strengthen human resources in various fields to reduce CO₂ emissions. Education in this context can be carried out at various levels. The education sectors targeted for carbon emissions education are kindergartens, primary schools, junior high schools, senior high schools, and college levels [15].

Table 8. Top keywords with minimum of 15 occurrences

Keywords	Occurrences	Total Link Strength
Carbon	110	582

Carbon emissions	90	500
Climate change	97	422
China	78	405
Emissions control	66	393
Carbon dioxide	71	362
Human	49	343
Education	67	329
Sustainability development	71	311
Carbon footprint	50	287
Greenhouse gases	36	230
Greenhouse gas	36	224
Environmental policy	28	209
Environmental economics	28	180
Environmental impact	27	175
Environmental protection	24	162
Sustainability	42	156
Energy efficiency	35	148
Gas emissions	22	144
Engineering education	37	143
Energy	27	142
Male	16	133
Energy conservation	19	131
Carbon emission	27	125
Low carbon	31	125
United States	20	122
Environmental education	32	115
Environmental management	22	111
Urbanization	18	109
Energy use	19	104
Energy utilization	18	98
Global warming	16	98
Public policy	17	98
Energy policy	21	97
Energy consumption	17	90
Mitigation	19	90
Decision making	19	86
Perception	16	65
Carbon sequestration	15	61
Higher education	19	46

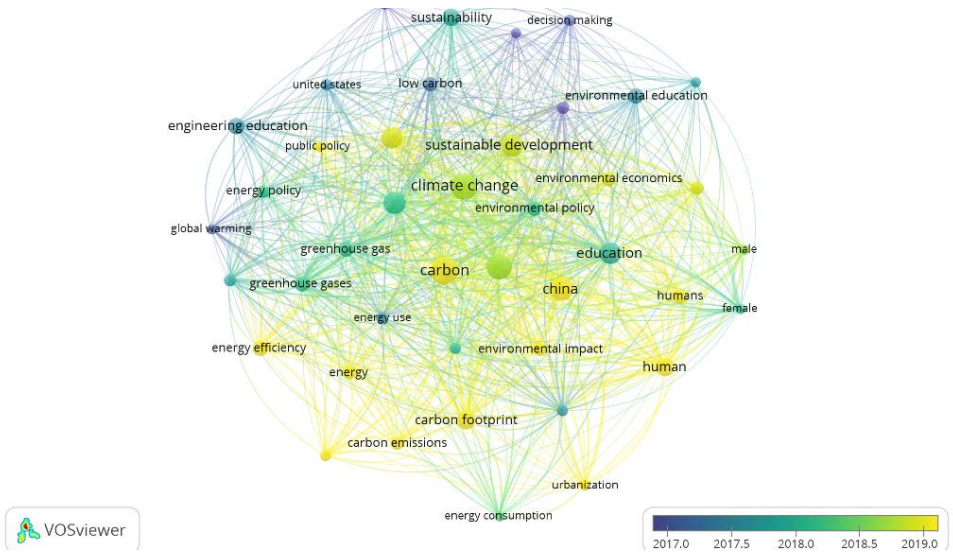


Fig 7. Overlay of Keywords with at Least 15 Occurrences

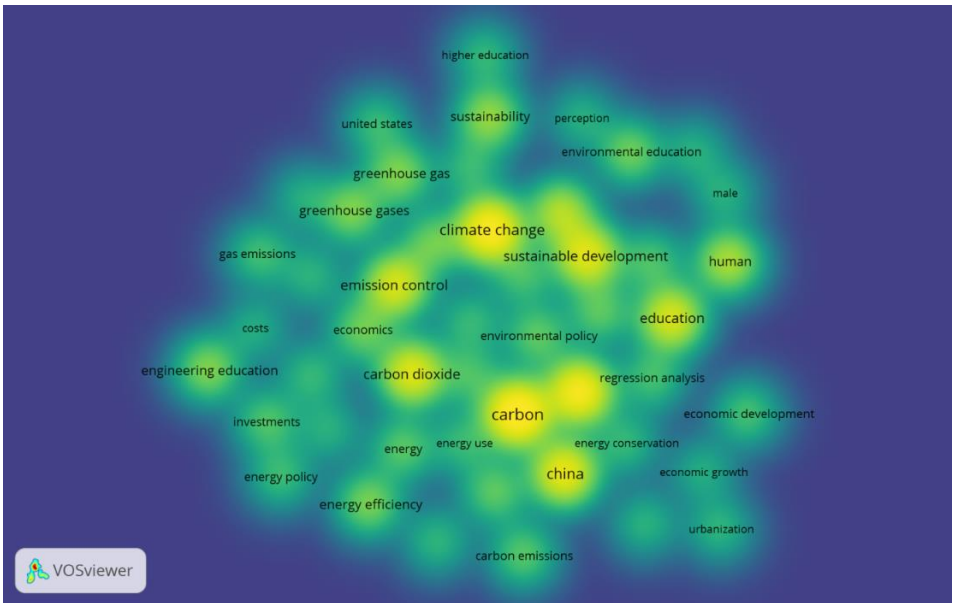


Fig 8. Keyword Density

As shown in Figure 8, the keyword from the field of education that appears in this study is "higher education." As far as this research is concerned, low carbon education activities are limited to the scope of higher education. Related keywords representing the topics of the articles are visualised in a network, as presented in Figure 7.

Low Carbon Education and What is Next to be Researched about It?

The research topics in the bibliometric analysis are interconnected with each other. A case in point is that the keywords "higher education" and "low carbon" are closely situated. In other words, the two topics are related. This shows that they are complementary to each other, indicating how low carbon research is conducted in higher education. In comparison, the topic "education" is located quite far from "higher education" and "low carbon", meaning that the relationship between them is still minimal. Therefore, further research is needed to explore such a relationship.

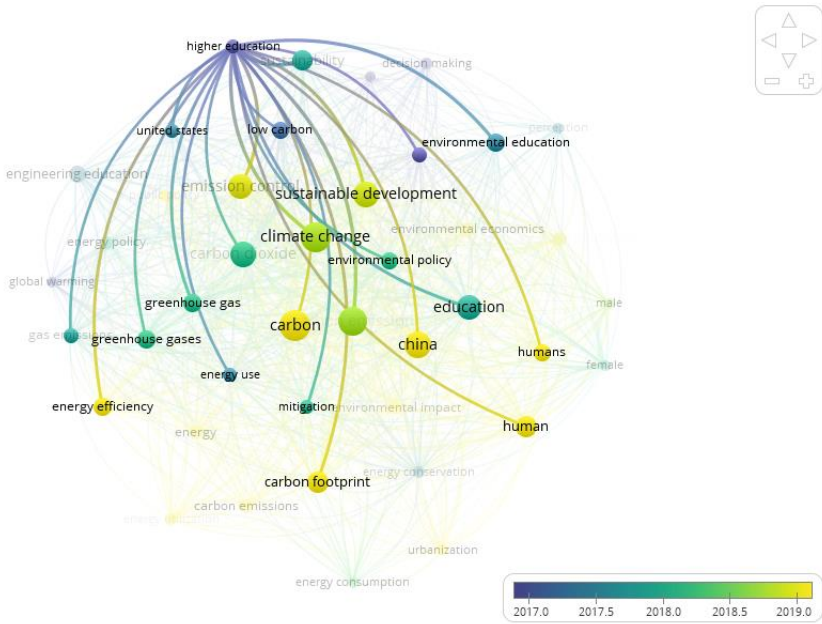


Fig 9. Novelty of Higher Education Research Relationships

This aligns with the research of Y. Wang & Vasques (2022), which indicates that few higher education institutions develop learning approaches to fostering student competence in climate change education (CCE). Some recommendations have been offered to universities in organizing CCE: they should organize multidisciplinary lectures, strengthen the curriculum, conduct training for academic staff, and collaborate on climate change in education and research (17). Specifically, the improvement of teacher professionalism in teaching CCE is emphasized (18). Universities also need to continue to focus on improving environmentally friendly attitudes and behaviours that have a holistic impact (19).

In this regard, the development of "low carbon" research can also be investigated more deeply. "Low carbon" is a method of reducing CO₂ emissions. Based on the visualisation of the word network in Figure 10, "low carbon" is implemented in the forms of energy policy, engineering education, energy efficiency, and carbon emissions monitoring by measuring carbon emissions in the form of "carbon footprint". Future research can be based on the novelty of research. Based on Figure 10, the new topics "energy efficiency" and "carbon footprint" are shown in bright yellow. These topics have been recorded to be conducted since early 2019.

Low-carbon activities are part of how researchers control CO₂ emissions. This is evidenced by the close positioning of the keywords "low carbon" and "emissions control". Figure 11 visualises the actions taken to control carbon emissions.

Several keywords indicate how to control matters related to carbon emissions such as "energy use", "energy efficiency", "energy consumption", and "carbon footprint", with a link between "emissions control" and "education". In short, carbon emissions control can be conducted directly at the sources that cause increased carbon emissions or by strengthening public understanding by improving carbon emissions control through education.

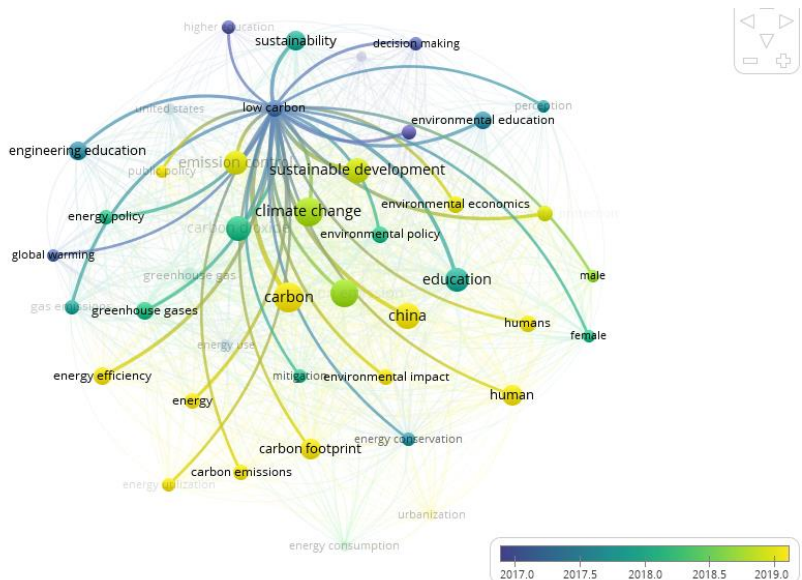


Fig 10. Relations of Keywords in Low Carbon Research

Some previous research has revealed a low understanding of carbon emissions among people engaged in teaching. Teachers in Finland cannot distinguish between climate change mitigation actions which have a small and significant impact on CO₂ emissions (20). Prospective teachers in Ghana are still confused about the concept of climate change (21). Prospective teachers in the Philippines have low

attitudes towards climate change education (22). Teacher candidates in Spain need to improve their understanding of climate change (23). Teacher candidates in Finland have not been able to play a role in climate change mitigation actions and even tend to blame others (24). In western Norway, teachers are reluctant to teach CCE (25). Finally, science teachers in America and Finland require additional training in CCE (26,27).

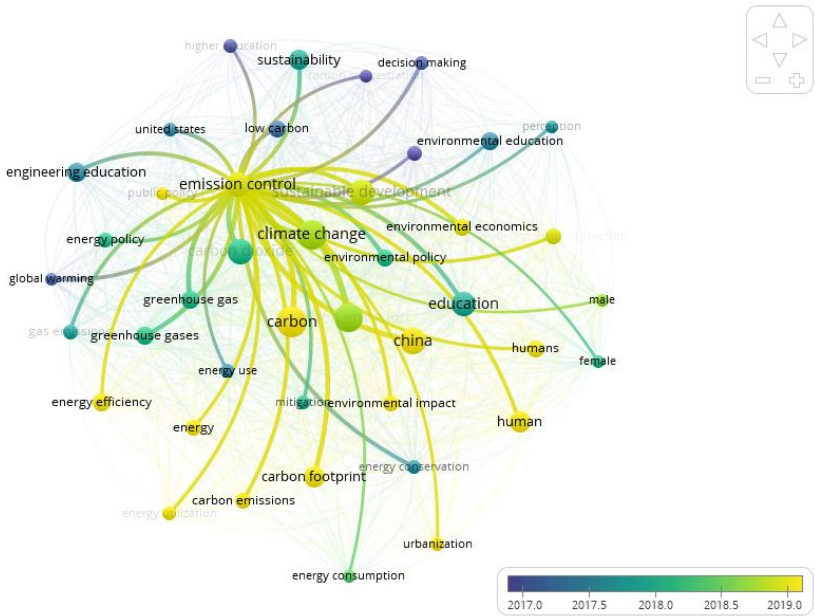


Fig 11. Renewed Emissions Control Research Relations

Table 9. Ten Most Recent Articles (2023)

No	Year	Authors	Title	Source Title	Cites	Publisher
1	2023	Lan J., Li Q., Zheng Y., Liu Z.	The Impact of The Low-Carbon City Pilots Programme on Industrial Land Transfer by Local Governments in China	Economic Analysis and Policy	1	Elsevier B.V.
2	2023	Qiu D., Xue J., Zhang T.,	Federated Reinforcement Learning for Smart Building Joint Peer-To-Peer Energy and Carbon Allowance Trading	Applied Energy	1	Elsevier Ltd

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| 3 | 2023 | Tan Y.,
Ying X.,
Gao W.,
Wang
S., Liu
Z. | Applying An Extended Theory
of Planned Behaviour to
Predict Willingness to Pay for
Green and Low-Carbon
Energy Transition | Journal of
Cleaner
Productio
n | 1 | Elsevier
Ltd |
| 4 | 2023 | Yang
G.,
Wang
F., Deng
F.,
Xiang
X. | Impact of Digital
Transformation on Enterprise
Carbon Intensity: The
Moderating Role of Digital
Information Resources | Internatio
nal
Journal of
Environm
ental
Research
and Public
Health | 1 | MDPI |
| 5 | 2023 | Perkins
D.H. | Structural Challenges to
Sustained Economic Growth
in China | China and
World
Economy | 1 | John
Wiley and
Sons Inc |
| 6 | 2023 | Cano
N.,
Berrio
L.,
Carvajal
E.,
Arango
S. | Assessing the carbon
Footprint of a Colombian
University Campus Using the
UNE-ISO 14064-1 and
WRI/WBCSD GHG Protocol
Corporate Standard | Environm
ental
Science
and
Pollution
Research | 1 | Springer
Science
and
Business
Media
Deutschla
nd GmbH |
| 7 | 2023 | Pelé-
Peltier
A.,
Charef
R.,
Morel
J.-C. | Factors Affecting the Use of
Earth Material in Mainstream
Construction: A Critical
Review | Building
Research
and
Informatio
n | 1 | Routledge |
| 8 | 2023 | Yang Y.,
Sun R.,
Wang
Y., Zhu | Evolutionary Analysis of
Resident Groups' Intention to
Participate in Green Retrofit
PPP Projects of Traditional
Apartment Complexes | Scientific
Reports | - | Nature
Research |

M.,
Yang P.

9	2023	Roberts M., Allen S., Clarke J., Searle J., Coley D.	Understanding the Global Warming Potential of Circular Design Strategies: Life Cycle Assessment of a Design-for-Disassembly Building	Sustainable Production and Consumption	-	Elsevier B.V.
10	2023	Pradhananga P., Elzomor M.	Developing Social Sustainability Knowledge and Cultural Proficiency among the Future Construction Workforce	Journal of Civil Engineering Education	-	American Society of Civil Engineers (ASCE)

In this case, the keyword "energy consumption" has the farthest distance from the others. This shows that there are only few links or only few people conducting research using this keyword. As Figure 11 indicates, several newly emerging themes, including "energy efficiency" and "carbon footprint", which are presented in yellow, need to be investigated. It is necessary to study further the aforementioned themes in combination with "education". Of the latest publications in 2023 (shown in Table 9), only one is concerned with higher education, indicating the need to further research low carbon education in the higher education environment.

The Latest Trends in Low Carbon Education Research

The latest trending research related to "low carbon" is presented in Table 9. The latest research articles have been dominated by the implementation of various solutions in several fields to reduce CO2 emissions. In other words, the research focuses on the implementation of "low carbon". This implementation serves two functions: direct emissions suppression at the emissions sources and education or setting an example for the community in implementing climate change mitigation and adaptation. Apart from implementing several practical solutions in reducing carbon emissions. There are several points that need to be improved to improve low carbon education at universities. Lack of awareness and lack of materials/resources are some of the obstacles in implementing low carbon education. Apart from that, there is also the need to increase the attractiveness to students of low carbon topics(28).

4. Conclusions

This bibliometric study was conducted with the keyword "Low Carbon Education" using the Scopus database. Data analysis used the VOSviewer and PoP software. The initial search obtained 917 articles and 19,022 citations (952.10 citations/year). After further selection by studying the abstracts, 456 articles and 7,379 citations were obtained (343.06 citations/year)—the selection results from 2003 to 2023 were equal to the results when the starting point was the year 2006. The next step was an in-depth analysis to answer the research questions.

The first question is "How is the development and distribution of low carbon education research?". Based on the study results, the number of low carbon education research publications from 2006 to 2023 increased. Then, an analysis was conducted to answer the questions of who were the leading researchers in low carbon education research and how they collaborated. An analysis of the publication network between countries with minimum criteria of five documents per country and five citations per country using the VOSviewer software obtained 27 countries meeting the criteria. In this bibliometric study, research with the theme "low carbon education" has been dominated by China, the USA, and the UK. The research is relatively evenly distributed in various continents, except for Africa.

The analysis revealed that 1,420 authors produced 456 articles. In visualising the authorship network, the parameter of each author having at least three articles is used. The authors have been dominated by those from China; the top three authors have been Zhang I. (8 documents, 136 citations, and 14 networks), Chen H. (6 documents, 120 citations, and 12 networks), and Wang C. (7 documents, 187 citations and 11 networks). Generally, productive journals have Quartile 1, except for the journal Buildings and Cities. The most productive publisher in this study has been Elsevier Ltd.

Authors' Contributions

First author: conceived and design the analysis, collect data, contributed data, wrote article, Second author: other contribution, Third author: other contribution.

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