GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2024 Volume 40 Issue 4 Pages 5–20

DOI: 10.24425/gsm.2024.152715

JACEK MISIAK[1], BARBARA ULIASZ-MISIAK[2]

Coal research trends – a bibliometric approach

Introduction

Coal is a caustobiolite – a combustible sedimentary rock of organic origin containing predominantly the elements carbon and oxygen, hydrogen, azote, and sulfur. Coal is classified into four main types, or ranks: anthracite, bituminous, sub-bituminous, and lignite. The ranking depends on the types and amounts of carbon the coal contains and on the amount of heat energy the coal can produce (Alpern and Lemos de Sousa 1998).

Coal is primarily an energy resource used by mankind for several hundred years. It is used in industry to produce electricity and heat, as well as in various types of manufacturing processes. It is also a raw material used in the production of medicines, cosmetics, fertilisers, and many others. Four basic uses for coal are usually cited (Borowiecki et al. 2008; Stańczyk 2008; Roga and Tomków 1971):

✉ Corresponding Author: Jacek Misiak; e-mail: misiak@agh.edu.pl

[1] AGH University of Kraków, Faculty of Geology, Geophysics and Environment Protection, Poland; ORCID iD: 0000-0002-0708-728X; e-mail: misiak@agh.edu.pl

[2] AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Kraków, Poland; ORCID iD: 0000-0001-8742-7100; e-mail: uliasz@agh.edu.pl

1) combustion to generate electricity and heat (pulverised coal combustion, fluidised bed combustion, combustion in oxygen in a chemical loop);
2) coking to produce metallurgical and heating coke;
3) gasification (using gas generators and underground gasification (Białecka 2008) with the production of electricity, gaseous fuel, liquid fuel and chemical products (high-temperature conversion of coal to synthesis gas consisting of carbon monoxide and hydrogen) – this is also a prospective technology for the production of hydrogen;
4) liquefaction to produce liquid fuels by interacting with coal using a solvent under elevated pressure and temperature conditions, followed by hydrocracking with hydrogen and a catalyst (Szuba and Michalik 1992).

In addition to these usually mentioned technologies, those related to coal mining and processing are also very important. In addition, methane (Coal Bed Methane) is extracted from coal seams using increasingly sophisticated technologies, e.g. Enhanced Coal Bed Methane associated with the intensification of methane extraction with simultaneous storage of carbon dioxide.

Coal is a cheap and accessible source of energy. However, the environmental costs associated with its exploitation and combustion are increasing. Coal mining is often accompanied by environmental degradation and combustion generates large amounts of carbon dioxide. Gas, which is a major contributor to global climate change.

Climate change occurring across the globe is a fact, undeniable by most scientists. For the most part, human activities related to atmospheric emissions of greenhouse gases are assumed to be their cause (Myhre et al. 2013; Bindoff et al. 2013). The main sources of greenhouse gases emitted by humans are energy, industry, and agriculture. The largest amounts of greenhouse gases come from the combustion of fossil fuels for energy purposes. Fossil fuel combustion processes mainly emit carbon dioxide; in 2019, emissions of this gas from energy accounted for 65% of total global greenhouse gas emissions (UNEP 2020).

Efforts to reduce emissions have been underway for several decades. Such initiatives include the United Nations Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gas emissions adopted in 1992 and the Paris Agreement signed in 2015 (Liu et al. 2020). Among other things, the agreement aims to achieve carbon neutrality by the second half of the 21st century. The European Union is also taking active steps to reduce emissions, having set itself greenhouse gas reduction targets in the Energy and Climate Package and Law, as well as in the 2019 Green Deal document (Communication from the Commission – The European Green Deal 2019). In June 2021. The European Parliament approved the EU Climate Law, which aims to make climate neutrality legally binding in the EU by 2050, setting an interim target of a 55% reduction in carbon dioxide emissions by 2030 (European Climate Law 2021).

The world and Europe are moving away from coal as a fuel, decarbonisation is one of the tenets of reducing carbon emissions. The leap to clean and sustainable energy will require a huge financial and technological investment. We need to invest in new technologies that will allow us to use coal more efficiently and reduce its negative impact on the environ-

ment. A way to manage this resource is through new technologies categorised as "clean coal technologies", which include the production of low-carbon coal fuel, the use of coal in the chemical industry, or the exploitation of the methane contained in coal (Marcisz et al. 2017; Matuszek et al. 2016).

Widely used across scientific disciplines, bibliometric analysis sets the pattern for the distribution of scientific data across specific subjects, fields, institutions, and countries, enabling quantitative analysis of the academic literature using mathematical and statistical techniques (Peng et al. 2018). Bibliometric analysis is crucial for understanding the research conducted to date, the current status, identifying relevant carbon and coal research, and identifying knowledge gaps to identify new research directions and strategies.

This article aims to analyse carbon and coal-related research topics in the period covering 1950–2023. To indicate the variability in topics, research areas, and countries. On this basis, an attempt is made to identify forward-looking, leading carbon-related research topics and to identify constraints and barriers to the development of this research topic.

1. Methods

The bibliometric analysis of coal-related publications was carried out in several stages:

- Stage 1: Analysis of the problem (selection of the bibliographical database, formulation of search phrases, selection of search options, selection of period);
- Stage 2: Data collection (collecting and verifying search results, exporting results to appropriate formats, exporting the final list to dedicated software);
- Stage 3: Bibliometric analysis (co-occurrence of keywords, cluster analysis);
- Stage 4: Research trend analysis.

The SCOPUS database was chosen as the bibliographic database to search for publications. This is a bibliographic database of abstracts and citations of peer-reviewed scientific publications, which also includes analytical tools. It contains approximately 97.3 million publication records from scientific publishers worldwide, including more than 28,300 active serial titles and 368,000 books (Elsevier 2024). It is one of the largest bibliographic abstracts and citation databases. Scopus is a curated database, meaning that content is selected for inclusion in the database through a rigorous process. Publications included in the Scopus database are selected based on criteria of scholarly quality and rigour. Scopus indexes many different elements of scientific publications, such as the publication title, abstract, keywords, author names, and related affiliations (Baas et al. 2020; Lim et al. 2024).

In the initial search of the Scopus database, the phrase "CARBON" was selected. The results were far beyond the scope of the intended research. To narrow the research area, the search was limited to records containing the phrase "COAL", which refers to a rock (fossil fuel). This phrase adequately describes the subject of the research being conducted. Areas of research for further analysis were identified from these searches. Searches were carried out for a time range covering the years 1950–2023. To include the entire completed calendar

year in the analysis, the search was terminated in 2023. The search was conducted from 10–20 August 2024. The search algorithm used was not limited to any scientific field or discipline. It was open-ended.

In the second step, after a preliminary check of the search results, the final list was exported to an external Excel file. The following criteria were used for further analysis: year, subject area, and country.

The work carried out in stages 1 and 2 allowed for a third stage in which bibliometric analyses (co-occurrence of words and clusters) were carried out (Zupic and Čater 2015). The scope of the research carried out included:

- Identification of the main subject areas of publications in the Scopus database related to the research area under analysis within the time horizon.
- Identification of countries of key relevance to the study area analysed based on the number of publications in the Scopus database.
- Identification of research sub-areas in the bibliometric dataset based on analysis of the most frequent phraseological compounds in the Scopus database using VOSviewer.

To identify research trends, the subject area indicated for publications containing the word "COAL" in the timeframes 1950–1975, 1976–2000, and 2001–2023 was analysed. The analysis was performed for publications from EU countries and the United Kingdom, compared to the countries with the highest number of publications USA, China, Australia, Canada, and India.

A bibliographic coupling method was used to identify sub-areas (revealing the structure of recent literature and identifying future potential research questions). The VOSviewer2 tool was used to implement this. The software is used to analyse various types of bibliometric data related to, for example, the number of citations, the occurrence of words and terms, the content of the text, or the relationships between researchers. VOSviewer can group related items by colour coding and allows the construction and viewing of bibliometric maps (van Eck and Waltman 2010).

An analysis of the research sub-areas was conducted for keywords from articles indexed in the SCOPUS database containing the word "COAL". For this purpose, co-word analysis was used. The co-occurrence analysis method is based on counting the frequency of the appearance of word pairs in the analysed text. It makes it possible to identify phraseological associations or regularities of co-occurrence of words. The co-occurrence of words can signal the existence of research sub-areas or identify indications for further development of a research area (Börner et al. 2003).

Using VOSviewer2 software, clusters of groups of analysed terms were distinguished. The cluster analysis was performed on the full group of items indexed in SCOPUS containing the following keywords used in the search: "COAL" and "ENGINEERING", "COAL" and "ENERGY", "COAL" and "GEOLOGY", "COAL" and "ENVIRONMENTAL", "COAL" and "ECONOMIC". The analysis was carried out to identify the most frequently raised research issues. Also, those that emerged as new and began to dominate the overall research themes.

2. Results and analysis

After searching the Scopus database using the phrase "CARBON", 2,726,076 records were returned. Of these, the largest number 2,228,394 are for the article, 283,181 for conference paper 103,462 for review, and 56,693 for book and book chapter. The searched records cover the following subject areas (Figure 1): Chemistry; Materials Science; Engineering; Environmental Science; Physics and Astronomy; Chemical Engineering; Biochemistry, Genetics, and Molecular Biology; Energy; Medicine; Agricultural and Biological Sciences; Earth and Planetary Sciences; Pharmacology, Toxicology and Pharmaceutics; Computer Science; Immunology and Microbiology; Mathematics; Social Sciences; Multidisciplinary; Business Management and Accounting; Economics, Econometrics and Finance; Neuroscience, Arts and Humanities; Decision Sciences; Nursing; Veterinary; Health Professions; Dentistry; Psychology; Undefined.

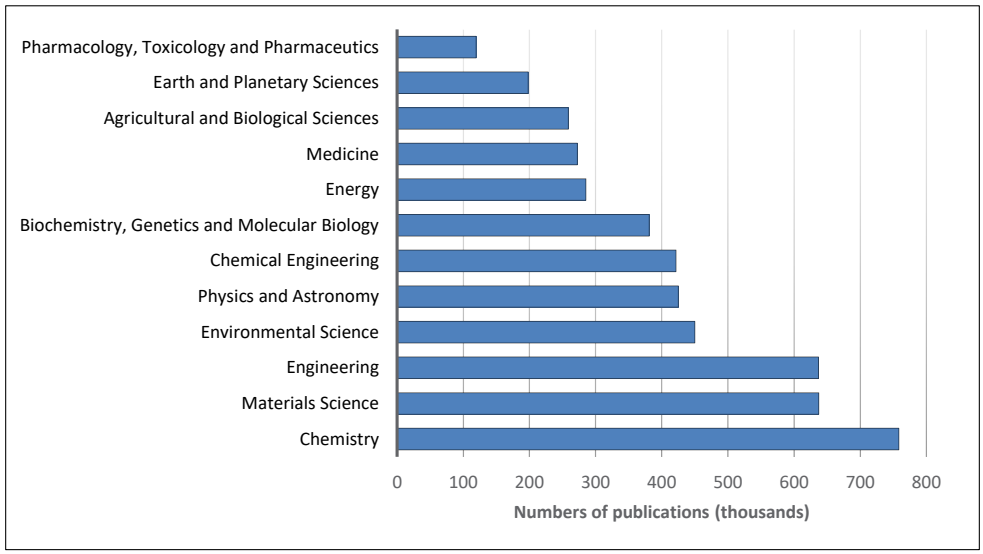

Fig. 1. Subject areas in the articles that contain the keyword "CARBON"

Rys. 1. Obszary tematyczne w artykułach zawierających słowo kluczowe „CARBON"

After searching the Scopus database using the phrase "COAL", 354,072 records were returned. Of which the largest number 254,202 are for the article, 283,181 for conference paper 72,210, 9,171 for review, and 7,992 for book and book chapter. The searched records cover the following subject areas: Engineering; Energy; Earth and Planetary Sciences; Environmental Science; Chemical Engineering; Chemistry; Materials Science; Physics and Astronomy; Medicine; Computer Science; Social Sciences; Agricultural and Biological Sciences; Mathematics; Business, Management, and Accounting; Biochemistry, Genetics

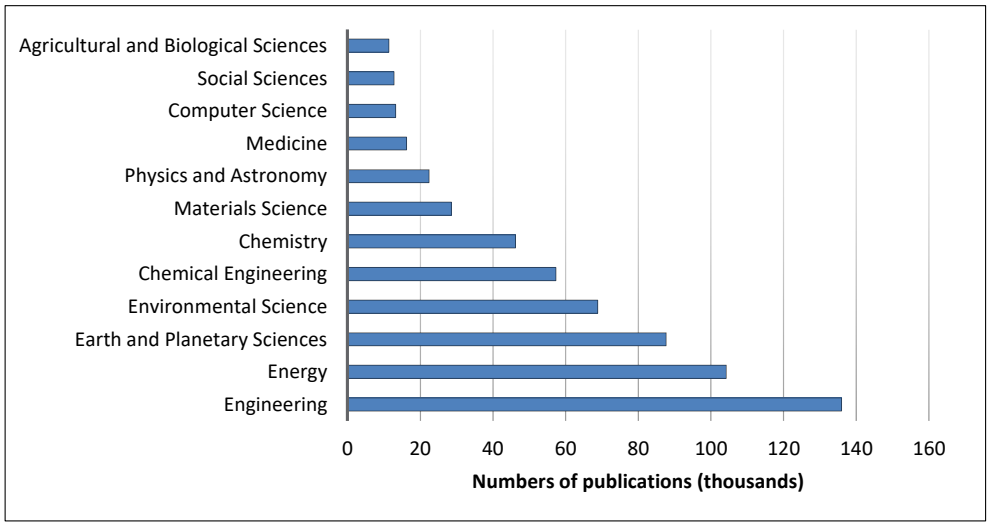

Fig. 2. Subject areas in the articles that contain the keyword "COAL"

Rys. 2. Obszary tematyczne w artykułach zawierających słowo kluczowe „COAL"

and Molecular Biology; Multidisciplinary; Economics, Econometrics and Finance; Arts and Humanities; Pharmacology, Toxicology and Pharmaceutics; Decision Sciences; Immunology and Microbiology; Health Professions; Neuroscience; Psychology; Nursing; Dentistry; Undefined; Veterinary.

The subject areas of searches using the words "CARBON" (as an element) and "COAL" (as a rock) differ considerably. A broader subject area is obtained with the word "CARBON" than with the search term "COAL". In addition, the subject areas searched using the word "COAL" are almost entirely contained in the search area using the word "CARBON". The results for the word "CARBON" extend far beyond the scope of the query. The records associated with the phrase "COAL" narrow the search area to a subject that includes the rocks (fossil fuels) that are the subject of the research undertaken. Based on these searches, research areas were identified for further analysis.

Analysis of the searches in the adopted time frames covering 1950–1975, 1976–2000, and 2001–2024 makes it possible to observe changes in research topics over 75 years in 25-year intervals. Searches using the word "COAL" subject areas such as Engineering, Energy, Earth and Planetary Sciences, Environmental Science, and Chemical Engineering were analysed in this case (Figure 3).

The analysis shows that research topics have changed considerably over the study period (75 years), as can be seen from the percentage of publications in the individual Subject areas. Particularly noticeable is the increase in publications in the field of Energy 8.4% from 1950–1975 through 15.1% from 1975–2000 to 16.8 from 2001–2023. The largest increase is,

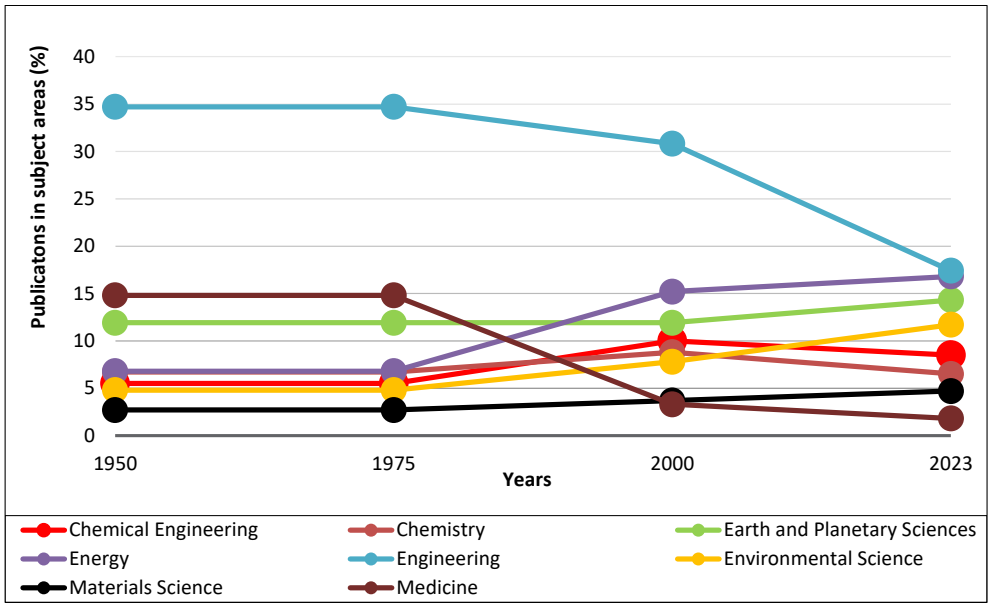

Fig. 3. Number of publications from 1975 to 2023 containing the keyword "COAL" in subject areas

Rys. 3. Liczba publikacji zawierających słowo kluczowe „COAL" w poszczególnych obszarach badawczych w latach 1975–2023

however, in the field of Environmental Science, where the share was 4.8% from 1950–1975 through 7.7% from 1975–2000 to 11.7% from 2001–2023.

The observed changes in research topics over the analysed 75-year time span allow us to conclude that they mainly concern topics related to Environmental Science. These themes are directly related to the pro-environmental measures taken in various countries in recent years. These actions are mainly related to the reduction of greenhouse gas emissions. Their main sources are energy, industry, agriculture, landfills, and transport. The largest amounts of greenhouse gases containing mainly carbon dioxide come from the combustion of fossil fuels for energy purposes. The interest in this topic in different countries has changed significantly over time (Figure 4). Particularly significant is the change that occurred after 2000, when there was a rapid global increase in publications on this topic. Between 1950 and 2000, there were a total of 4,363 publications indexed in the SCOPUS database. At the same time, there was a significant increase in the number of publications from China observed in the period under review from 177 publications in 1950–2000 to 12911 in 2001–2023. This change is particularly evident in the percentage increase in the total number of publications worldwide from 1% to 29.9%). In the case of the number of publications from the USA, the opposite trend of a decrease from 71.6% in the period 1950–1975 to 14.3% in the period 2001–2023 is apparent in the corresponding periods. For the other countries, no such rapid changes in the number of publications are observed.

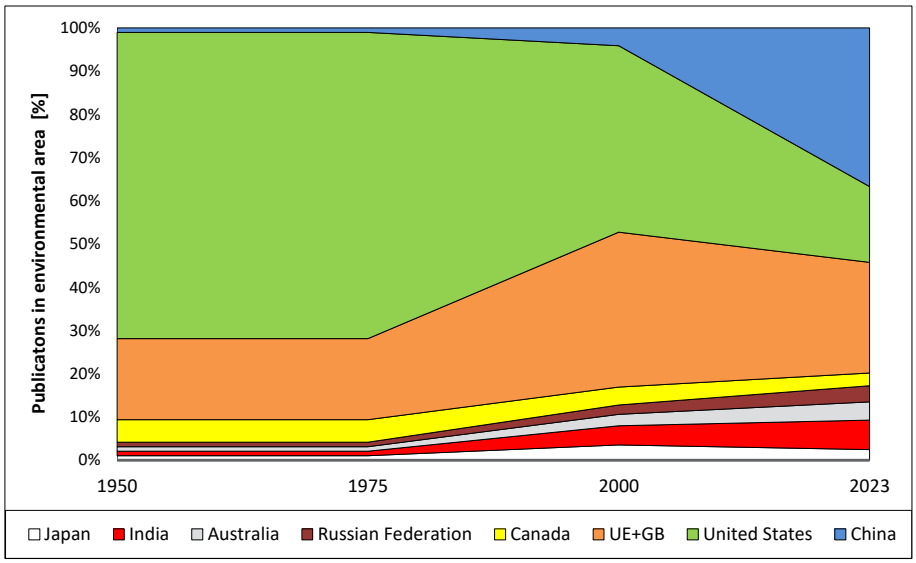

Fig. 4. Number of publications with the keyword "COAL" in the field of environmental sciences from the EU and other countries, 1975–2023

Rys. 4. Liczba publikacji zawierających słowo kluczowe „COAL" związanych z tematyką Environmental Science z UE i innych krajów w latach 1975–2023

To identify research areas, data were extracted from the SCOPUS database for analysis using VOS software (https://www.vosviewer.com). The retrieved records contained data that were extracted using the following keywords used for the search: "COAL" and "ENGINEERING", "COAL" and "ENERGY", "COAL" and "GEOLOGY", "COAL" and "ENVIRONMENTAL", "COAL" and "ECONOMIC". Analysis of the retrieved data made it possible to distinguish three research areas (items) (Figure 5) highlighted by colours, respectively: green – GEOLOGY & MINING, blue – TECHNOLOGY, red – ENVIRONMENT & ENERGY & ECONOMY. Within each research area, there are keywords whose frequency of occurrence is illustrated by the size of the circle, and the connecting lines illustrate the bibliographic links occurring between each word.

For the individual research sub-areas, it is possible to distinguish groups of keywords occurring with the greatest frequency and most accurately reflecting the research topic (Table 1) within the environment, energy, and economics topic, the most frequent keyword is carbon dioxide occurring 664 times and is related to the environmental topic. The next most frequent keywords related to this topic and ranking in the top ten are gas emission, carbon, coal storage, environmental impact, and greenhouse gases. The most frequently used technology keywords are coal combustion, lignite, combustion, coal ash, fly ash, bituminous coal, water, quality control, chemical analysis, and particle size. The keywords most frequently associated with the topics of mining and geology are coal deposits,

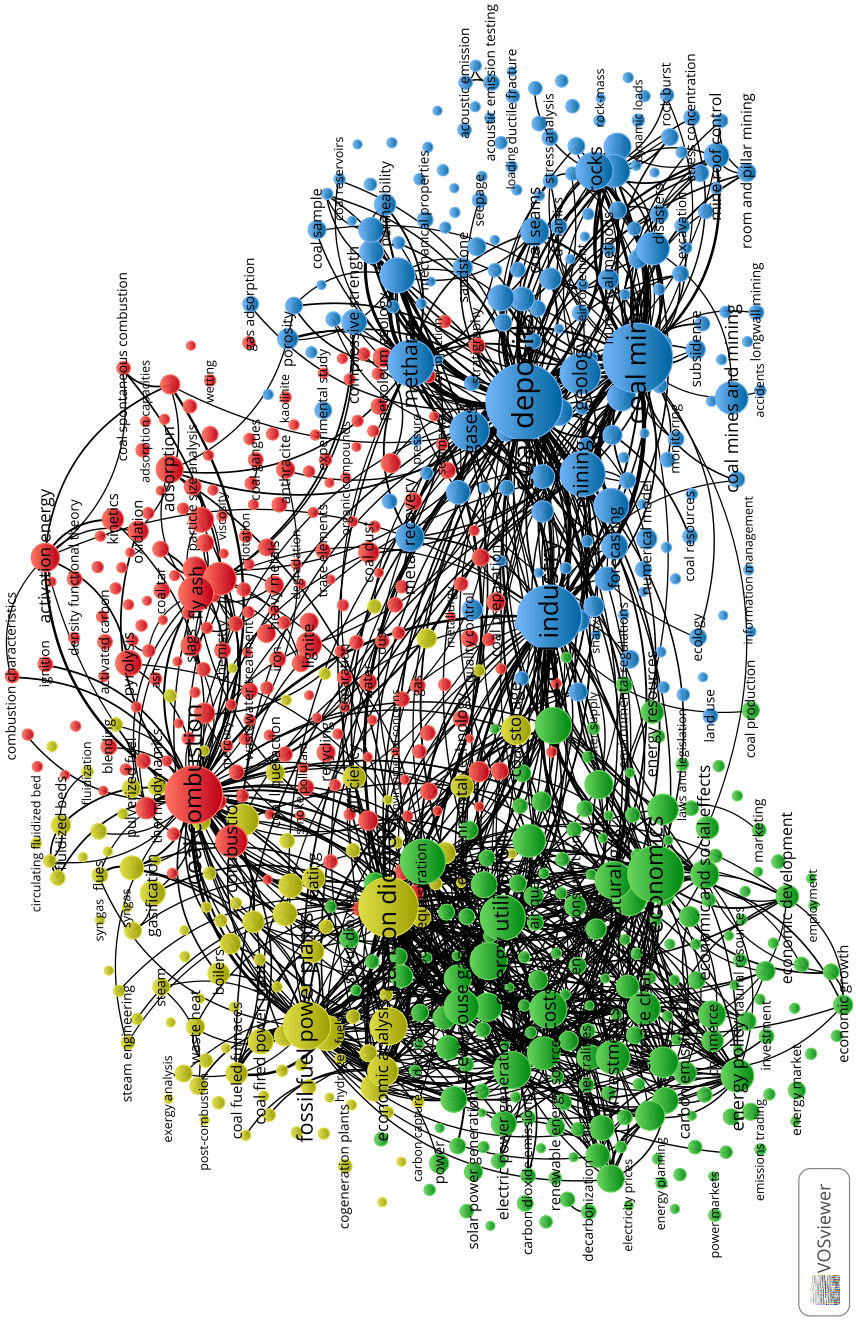

Fig. 5. Keyword map related to GEOLOGY & MINING (blue), TECHNOLOGY (red), ENVIRONMENT & ENERGY & ECONOMY (green)

Rys. 5. Mapa słów kluczowych związanych z GEOLOGIĄ I GÓRNICTWEM (niebieski), TECHNOLOGIĄ (czerwony), ŚRODOWISKIEM, ENERGIĄ I GOSPODARKĄ (zielony)

Table 1. Keywords with the highest frequency of occurrence in selected research topics

Tabela 1. Słowa kluczowe występujące z największą częstotliwością w wybranych tematach badawczych

	Research topics					
	environment, energy and economics		technology		geology and mining	
	keywords	quantity	keywords	quantity	keywords	quantity
1	Carbon dioxide	664	Coal combustion	662	Coal deposits	675
2	Energy	654	Lignite	605	Coal industry	674
3	Gas emissions	649	Combustion	603	Mining	661
4	Energy utilization	647	Coal ash	587	Coal mines	660
5	Carbon	643	Fly ash	580	Gases	660
6	Coal storage	639	Bituminous coal	570	Methane	651
7	Environmental impact	636	Water	570	Metal recovery	646
8	Economics	630	Quality control	555	Coal mining	610
9	Greenhouse gases	630	Chemical analysis	553	Extraction	604
10	Fossil fuel power plants	618	Particle size	552	Risk assessment	598
11	Environmental protection	614	Adsorption	551	Forecasting	586
12	Emission control	613	Carbonization	551	Numerical model	583
13	Energy efficiency	608	Gas	550	Proven reserves	582
14	Sustainable development	605	Pollution	544	Geology	580
15	Costs	604	Anthracite	541	Coal mine	562
16	Environmental technology	603	Recycling	537	Groundwater	561
17	Global warming	603	Chemical industry	533	Computer simulation	560
18	Economic and social effects	597	Waste incineration	532	Digital storage	559
19	Efficiency	594	Slags	529	Gas industry	538
20	Coal-fired power plant	591	Waste disposal	524	Coal bed methane	528
21	Climate change	588	Comparative study	523	Experimental study	528
22	Cost effectiveness	582	Pollution control	523	Coal transportation	518
23	Energy conservation	581	Pyrolysis	515	Coal seam	507
24	Fossil fuels	577	Sulfur	514	Condition	503
25	Coal gasification	568	Moisture	513	Environmental engineering	499

	Research topics					
	environment, energy and economics		technology		geology and mining	
	keywords	quantity	keywords	quantity	keywords	quantity
26	Environmental management	567	Minerals	512	Compressive strength	492
27	Heating	565	Waste management	498	Coal-mining	481
28	Economic analysis	564	Coal dust	497	Porosity	475
29	Life cycle	557	Oxidation	494	Coal seams	464
30	Investments	554	Kinetics	491	Coal research	461
31	Cost benefit analysis	552	Water pollution	490	Numerical models	460
32	Thermoelectric power plants	549	Particle size analysis	482	Modelling	459
33	Air pollution	547	Sulfur compounds	482	Aquifers	450
34	Carbon emission	546	Economic geology	479	Mathematical models	450
35	Carbon capture	544	Environmental pollutions	477	Numerical simulation	449
36	Carbon sequestration	543	Iron	475	Energy dissipation	442
37	Environmental regulations	541	Desulfurization	468	Coal resources	441
38	Power generation	540	Fuel	468	Productivity	440
39	Energy resource	534	Heavy metals	463	Desorption	432
40	Fossil fuel	532	Recovery	462	Ecology	432
41	Coal fired power plant	531	Water treatment	457	Numerical methods	432
42	Gasification	529	Particulate matter	453	Rocks	430
43	Fuels	527	Separation	453	Coalbed methane	428
44	Power plants	523	Wastewater treatment	448	Limestone	423
45	Energy consumption	522	Chemistry	447	Coal gas	420
46	Industrial economics	522	Hydrocarbons	445	Mining engineering	415
47	Flue gases	514	Chemical composition	444	Neural networks	413
48	Greenhouse gas	514	Blending	442	Safety engineering	413
49	Energy storage	508	Waste treatment	440	Dynamics	410
50	Sulfur dioxide	508	Morphology	435	Land use	407

coal industry, mining, coal mine, gases, methane, metal recovery, coal mining, extraction, and risk assessment (Table 1).

Due to the variation in the formulation of keywords by the authors of publications the use of e.g. singular or plural (emission or emissions), the use of single words or phrases (efficiency or energy efficiency) keywords with the same meaning occur several times. Therefore, the quantities given in the table do not fully reflect the frequency of occurrence of certain words in the keywords.

Among the keywords in the analysed publications, "carbon dioxide" (frequency of use from 1950 to 2024 –18,370 times) is of particular note. The number of occurrences of this keyword increased in the analysed period from 41 publications in 1950–1975 to 17,434 in the period 2000–2023. Analysing the keywords in articles containing "COAL AND CARBON_DIOXIDE OR CO2", it is possible to distinguish several thematic groups concerning issues related to coal combustion, greenhouse gases and their reduction technologies, as well as coal processing technologies. Noteworthy is the emergence of topics related to carbon dioxide emissions, their environmental effects, and CO_2 reduction technologies (capture and geological storage). An analysis of the keywords used in publications during the period analysed best illustrates the changes that have taken place in interest in this topic (Table 2).

Table 2. Frequency of use of keywords in CO_2 research publications between 1950 and 2023

Tabela 2. Częstość użycia słów kluczowych w publikacjach badawczych dotyczących CO_2 w latach 1950–2023

Keywords	1950–1975	1976–2000	2001–2023
Carbon Dioxide	41	1,005	17,434
CO_2	0	0	2,453
CO_2 Emission(s)	0	0	2,866
Carbon Dioxide Emissions	0	46	741
Carbon Emission(s)	0	20	2,266
CCS	0	0	382
Carbon Capture And Storage	0	0	528
Carbon Sequestration	0	0	1,476
CO_2 Capture	0	0	3,428
Carbon Capture	0	0	2,142

Conclusions

This article describes a bibliometric analysis of coal-related publications, carried out in several stages. First, the SCOPUS database was selected search methods were defined, and then data were collected and subjected to bibliometric analysis and assessment of research trends. The results showed a significant evolution of research topics, especially towards environmental issues and CO_2 reduction. The analysis over the period 1950–2024 showed changing research interests. Particularly in the topics of energy and environmental sciences, there is a significant increase in publications, which is linked to the growing emphasis on pro-environmental measures such as the reduction of greenhouse gas emissions. After 2000, a sharp increase in the number of publications is noticeable, especially in China, which may indicate the country's growing commitment to environmental issues. The analysis using the VOS software made it possible to distinguish three main research areas on coal: environmental; technological; and geological mining. The most frequently occurring keywords were: "carbon dioxide" in the environmental area, "coal combustion" in the technological area, and "coal deposits" in the geological-mining area. The analysis of the research areas and trends related to the research topics supported by the number and affiliation of scientific publications and the keywords used by the authors allows conclusions to be drawn as to the future of specific research directions related to coal.

Changing energy and environmental priorities could limit the scope of certain areas of coal research. With increasing pressure to reduce CO_2 emissions and move to greener energy sources, research into traditional methods of burning coal in power stations may become less relevant. Less promising may be research into coal mining in regions where reserves are nearing depletion. Mining in such regions may cost more than the economic benefits.

High-emission coal mining and processing technologies may be phased out in favour of cleaner solutions. Research into the traditional uses of coal in heavy industry may become less relevant as the sector moves to more sustainable and low-carbon technologies. Given global efforts to decarbonise and shift to renewables, research into coal as a major energy source may be reduced.

Future coal research can focus on several key areas that can contribute to a more sustainable and efficient use of coal in the future. Research into technologies that minimise the environmental impact of coal mining and use, including reclamation of post-mining sites and reduction of emissions. Use of advanced technologies, such as artificial intelligence and automation, to improve the efficiency and safety of mining processes. Development of technologies that enable coal to be processed in a more environmentally friendly manner, including the production of alternative fuels and chemicals. Research into improving the energy efficiency of coal-fired power plants and carbon capture and storage (CCS) technologies. Exploring new uses for coal, such as the production of high value-added carbon materials, e.g. graphene, which has wide applications in electronics and other fields. Research into the optimal management of coal resources to ensure their long-term availability and minimise

negative environmental impacts. Research into how coal technologies can be integrated with renewable energy sources to create more sustainable energy systems.

Innovative applications of coal that go beyond its traditional use as a fuel, show that coal can be a valuable raw material in many modern technologies: Carbon can be processed into a variety of advanced materials such as carbon nanomaterials, activated carbons, and graphite. These materials find applications in computer memory devices, LED lighting, photovoltaic cells, batteries, capacitors, sorbents, catalysts, membranes, and medical imaging. Carbon is used to produce carbon fibers, which are lightweight but very strong. They are used in the aerospace, automotive, and sports industries and in the manufacture of advanced prosthetics. Carbon powder can be used in a variety of applications due to its high conductivity, thermal stability, and customisable properties. It is used in biosensors, electrodes, fertilisers, and as a medium for 3D printers. Activated carbon is widely used in medicine as a means to cleanse the body of toxins. In addition, carbon is used in the production of medical imaging materials.

This research was supported by the AGH University of Science and Technology research subventions No. 16.16.190.779 and No 16.16.140.315.

The Authors have no conflicts of interest to declare.

REFERENCES

Alpern, B. and Lemos de Sousa, M.J. 1998. *International Classification of In-Seam Coal*. United Nations, Geneva.

Baas et al. 2020 – Baas, J., Schotten, M., Plume, A., Côté, G. and Karimi, R. 2020. Scopus as a Curated, High-Quality Bibliometric Data Source for Academic Research in Quantitative Science Studies. *Quantitative Science Studies* 1(1), pp. 377–386, DOI: 10.1162/qss_a_00019.

Białecka, B. 2008. *Underground Coal Gasification*. Katowice: Central Mining Institute, 152 pp. (*in Polish*).

Bindoff et al. 2013 − Bindoff, N.L., Stott, P.A., Achuta Rao, K.M., Allen, M.R., Gillett, D., Gutzler, D., Hansingo, K., Hegerl, G., Hu, Y., Jain, S. Mokhov, I.I., Overland, J., Perlwitz, J., Sebbari, R. and Zhang, X. 2013 – *Detection and Attribution of Climate Change: From Global to Regional. In Climate Change 2013*. Cambridge University Press, pp. 867–952.

Börner et al. 2003 − Börner, K., Chen, C. and Boyack, K.W. 2003. Visualizing Knowledge Domains. *Annual Review of Information Science and Technology* 37(1), pp. 179–255, DOI: 10.1002/aris.1440370106.

Borowiecki et al. 2008 − Borowiecki, T., Kijeński, J., Machnikowski, J. and Ściązko, M. 2008. Czysta Energia. Chemical Products and Fuels from Coal – Evaluation of Development Potential. Institute for Chemical Processing of Coal, Zabrze.

Communication from the Commission – The European Green Deal (2019), COM(2019) 640 final. [Online:] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN [Accessed: 2024-09-24].

van Eck, N.J. and Waltman, L. 2010. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* 84(2), pp. 523–538, DOI: 10.1007/s11192-009-0146-3.

Elsevier 2024. *Scopus: Comprehensive, Multidisciplinary, Trusted Abstract and Citation Database*. [Online:] https://www.elsevier.com/products/scopus [Accessed: 2024-09-24].

European Climate Law 2021. [Online:] https://eur-lex.europa.eu/EN/legal-content/summary/european-climate-law.html [Accessed: 2024-09-24].

Lim et al. 2024 − Lim, W.M., Kumar, S. and Donthu, N. 2024. How to Combine and Clean Bibliometric Data and Use Bibliometric Tools Synergistically: Guidelines Using Metaverse Research. *Journal of Business Research* 182, DOI: 10.1016/j.jbusres.2024.114760.

Liu et al. 2020 − Liu, W., McKibbin, W.J., Morris A.C. and Wilcoxen P.J. 2020. Global Economic and Environmental Outcomes of the Paris Agreement. *Energy Economics* 90, DOI: 10.1016/j.eneco.2020.104838.

Marcisz et al. 2017 − Marcisz, M., Probierz, K., Chmielniak, T. and Sobolewski, A. 2017. Clean coal technologies – chance for development of mining sector (*Czyste technologie węglowe – szansą rozwoju sektora górniczego*). *Systemy Wspomagania w Inżynierii Produkcji* 6(3), pp. 121–136 (*in Polish*).

Matuszek et al. 2016 − Matuszek, K., Hrycko, P., Stelmach, S. and Sobolewski, A. 2016. Carbonaceous smokeless fuel and modern small-scale boilers limiting the residential emission. Part 1. General aspects (*Węglowe paliwo niskoemisyjne i nowoczesne konstrukcje kotłów małej mocy ograniczające "niską emisję". Cz. 1, Prezentacja problemu*). *Przemysł Chemiczny* 95(2), pp. 223–227, DOI: 10.15199/62.2016.2.8 (*in Polish*).

Myhre et al. 2013 − Myhre, G., Shindell, D., Bréon, F.M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T. and Zhang, H. 2013. Anthropogenic and Natural Radiative Forcing. In Climate Change 2013'. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Roga, B. and Tomków, K. 1971. *Chemical Technology of Coal* (*Chemiczna technologia węgla*). Warszawa: WNT (*in Polish*).

Stańczyk, K. 2008. *Clean Coal Utilisation Technologies* (*Czyste technologie użytkowania węgla*). Katowice: GIG (*in Polish*).

Szuba, J. and Michalik, L. 1992. *Liquid fuels from coal* (*Paliwa ciekłe z węgla*). Warszawa: WNT (*in Polish*).

UNEP 2020. *United Nations Environment Programme*. Emissions Gap Report 2020. Nairobi.

Zupic, I. and Čater, T. 2015. Bibliometric Methods in Management and Organization. *Organizational Research Methods* 18(3), pp. 429–472, DOI: 10.1177/1094428114562629.

COAL RESEARCH TRENDS – A BIBLIOMETRIC APPROACH

Keywords

coal, carbon, bibliometric analysis, research trend

Abstract

Coal is a cheap and accessible source of energy. However, the environmental costs associated with its exploitation and combustion are increasing. Burning coal generates large amounts of carbon dioxide. A gas that is a major contributor to global climate change.

Coal is a raw material used in various technologies (from energy to medicine) and is also the subject of scientific research. The directions for its use change over time. By tracing research trends related to coal, new research directions can be identified. Bibliometric analysis is used for this purpose, using a variety of data pertaining to scientific publications observed with the development of science. This method makes it possible to analyse networks of research, national and international, and to identify the internal logic of scientific development. This article aims to analyse research topics related to the word "coal" in the period covering 1950–2023. The article presents an analysis of publications indexed in the SCOPUS database. Publications that contained phrases related to search phrases containing the word "COAL" in the title, abstract, or keywords were included in the analysis. The

dynamics of changes in the interest of coal researchers in subject areas, research areas, and countries were presented. On this basis, an attempt was made to identify future leading research topics related to coal and to identify limitations and barriers to the development of this research topic.

KIERUNKI BADAŃ WĘGLA – ANALIZA BIBLIOGRAFICZNA

Słowa kluczowe

węgiel, analiza bibliometryczna, trendy badawcze

Streszczenie

Węgiel jest tanim i dostępnym źródłem energii. Jednak środowiskowe koszty związane z jego eksploatacją i spalaniem są coraz wyższe. Spalanie węgla generuje duże ilości dwutlenku węgla. Gazu, który jest głównym czynnikiem przyczyniającym się do globalnych zmian klimatu.

Węgiel jest surowcem wykorzystywanym w różnych technologiach (od energetyki po medycynę), a także przedmiotem badań naukowych. Kierunki jego wykorzystania zmieniają się wraz z czasem. Prześledzenie trendów badawczych związanych z węglem może pozwolić na wskazanie nowych kierunków badań. Do tego celu stosuje się analizę bibliometryczną wykorzystującą różnorakie dane odnoszące się do publikacji naukowych umożliwiającą obserwowanie trendów badawczych wraz z rozwojem nauki. Metoda ta pozwala na analizowanie sieci powiązań badawczych, krajowych i międzynarodowych oraz na identyfikację wewnętrznej logiki rozwoju nauki. Celem artykułu jest analiza tematów badawczych związanych ze słowem “coal” w okresie obejmującym lata 1950–2023. W artykule przedstawiono analizę publikacji indeksowanych w bazie SCOPUS. Do analizy włączono publikacje, które w tytule, streszczeniu lub słowach kluczowych zawierały wyrażenia powiązane z wyszukiwanymi frazami zawierającymi słowo “coal”. Przedstawiono dynamikę zmian zainteresowań badaczy zajmujących się węglem problematyką w: zakresach tematycznych, obszarach badawczych i krajach. Na tej podstawie podjęto próbę wyodrębnienia przyszłościowych, wiodących tematów badawczych związanych z węglem oraz wskazanie ograniczeń i barier w rozwoju tej tematyki badawczej.