Bibliometric Analysis of Renewable Energy Research and Industrial Assets in Poland and Slovakia

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Abstract. Renewable energy sources, such as wind, solar, hydro, and geothermal, play an increasingly important role in the global energy mix. They offer a sustainable alternative to fossil fuels, reducing greenhouse gas emissions and contributing to the fight against climate change. The development and deployment of renewable energy technologies have been growing rapidly worldwide, driven by government policies, technological advancements, and decreasing costs. Despite their advantages, renewable energy sources still face challenges, such as intermittency, storage, and grid integration. However, with continued investment and innovation, renewable energy sources have the potential to become the dominant source of energy in the future. The article presents a bibliometric analysis of renewable energy sources research in Poland and Slovakia. The study was based on publications indexed in the Scopus database. The analysis covered the period from 1990 to 2023. The study investigated the research topics related to renewable energy sources and analysis the most cited publications written by authors from the analyzed countries. Bibliometric analysis demonstrates the growing interest in renewable energy sources research in Poland and Slovakia. However, there is still a need for further research in certain areas, such as energy storage, smart grid technologies, and the use of renewable energy in transport. The results of this study can serve as a valuable resource for policymakers, researchers, and other stake-holders interested in promoting the development and use of renewable energy sources.

Keywords: Renewable energy · Bibliometric · Citespace

1 Introduction

In recent decades, there has been growing public awareness of the impact of greenhouse gas emissions on the Earth's climate and the need to reduce dependence on fossil fuels [1–5]. As a result, renewable energy sources have become one of the most important elements of the energy policy of many countries, including Poland and Slovakia [6–12].

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Renewable energy sources, such as solar, wind and hydropower, are gaining increasing importance worldwide as an alternative to fossil fuels [13–16]. The European Union's energy policy imposes an obligation on member countries to increase the share of energy from renewable sources in the overall energy mix [17–19]. Poland and Slovakia, as countries with a similar energy structure, are following this trend and intensifying investments in renewable energy sources.

Figure 1 shows the share of renewable energy in Poland and Slovakia from 2004 to 2021, according to Eurostat data [20].

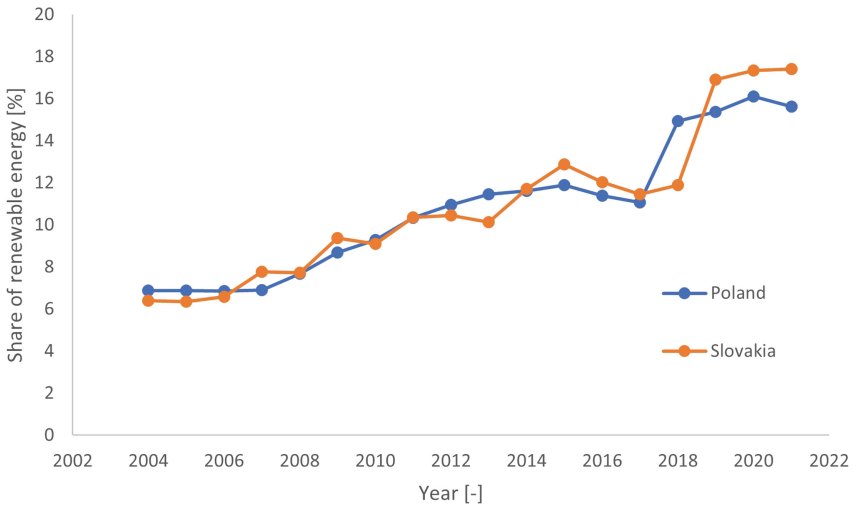

Fig. 1. Share of renewable energy in Poland and Slovakia according to Eurostat data [20].

Analyzing the chart above, it can be seen that Poland and Slovakia are characterized by very similar growth in the share of renewable energy. In 2021, Poland's renewable energy sources share was 15.6%, while Slovakia's was 17.4%. In 2020, both countries reached the target set by the European Union. Poland achieved the required 15%, while Slovakia achieved 14% of the renewable energy sources share in the energy mix.

Figure 2 shows the percentage share of each renewable energy source in Poland and Slovakia.

Despite the similar rate of development of renewable energy sources in Poland and Slovakia, the structure of energy generation from individual renewable sources is different (Fig. 2). The main renewable energy source for Poland is photovoltaics, which account for 54% of installed capacity. In Slovakia, the main source of renewable energy is hydroelectric power, which accounts for 77%. Table 1 shows the installed capacity of each renewable source in 2022.

When comparing the installed capacity of renewable energy sources, it is important to consider the total installed capacity of all power plants. In Poland, the total installed capacity is about 60 GW, while in Slovakia it is about 8 GW. This means that the total installed capacity of renewable energy sources in Poland is about 37% of the total installed capacity, while in Slovakia it is 41%. It should be noted, however, that energy

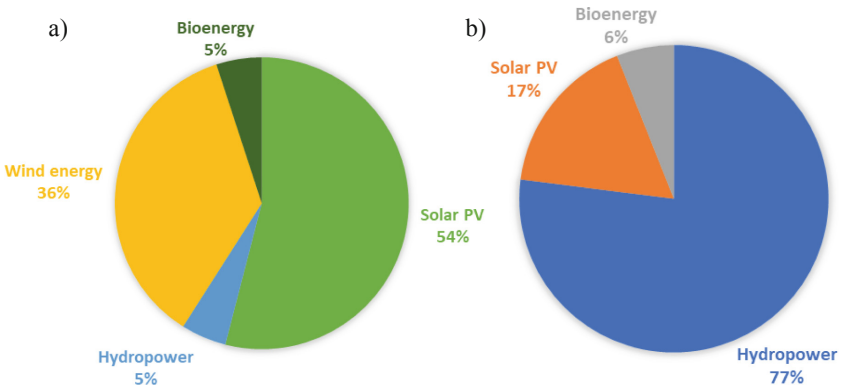

Fig. 2. Structure of renewable energy in a) Poland, b) Slovakia.

Table 1. Installed capacity in renewable energy sources

Installed capacity (MW)		
	Poland	Slovakia
Hydropower	978.0	2574.0
Bioenergy	1248.1	201.0
Solar PV	11, 924.0	573.0
Wind Energy	7864.8	3.0

from renewable sources such as photovoltaics and wind power is characterized by high variability and largely depends on weather conditions. Hydroelectric power plants, on the other hand, very often operate as peaking power plants, i.e. they work only during periods of peak energy demand. As a result, the actual energy obtained from renewable sources is lower than the installed capacity value would suggest.

The article presents a bibliometric analysis of research on renewable energy sources in Poland and Slovakia. The study was based on publications indexed in the Scopus database. The analysis covered the period from 1990 to 2023. The paper analyzes research topics related to renewable energy sources and examines the most cited publications by authors from the analyzed countries and the main research centers.

2 Bibliometric Analysis of the Literature

Bibliometric analysis is a method of studying scientific publications that is based on the use of statistical techniques to collect, process and analyze bibliographic data. The purpose of bibliometric analysis is to assess the impact of scientific publications on the development of a particular scientific field and to identify the most important authors, journals, topics and research centers [21–23].

For the analysis, CiteSpace software was used, which allows analysis of publications and citations and creates visualizations showing the network of connections between publications, authors, institutions and keywords. CiteSpace allows the generation of maps and graphs that show connections between scientific publications in a given research area. The program can detect trends and patterns in scientific publications, as well as identify key authors, institutions, research topics and scientific journals. CiteSpace allows analysis of bibliometric data from a variety of sources, including databases such as Web of Science, Scopus, PubMed and others.

This publication uses data from the Scopus database. "Renewable Energy" was used as the search criterion. Then, through filters, the country was set to Poland and then to Slovakia.

2.1 Bibliometric Analysis for Poland

Figure 3 shows an analysis of publications by authors' affiliations. Through this analysis, it is possible to determine which institutes are most involved in renewable energy research.

Based on Fig. 3, Table 2 was made, which shows the 15 centers with the highest number of publications and the corresponding centrality coefficient. The centrality coefficient in bibliometric analysis signifies how important a node is in the network and its role in connecting other nodes. In the case of bibliometric analysis, this coefficient can help identify authors, universities or publications that play a central role in a particular field of scientific research. This means that publications from universities with the highest centrality index, characterize the greatest innovation and are the most frequently cited.

Based on the analysis performed, it can be concluded that for the adopted criteria, the highest number of publications is shown by AGH University of Krakow, while the highest centrality coefficient, which indicates the key role in research on renewable energy sources, has the Polish Academy of Sciences, which means that the research done by its scientists is most often cited.

Figure 4 shows an analysis of citations by major areas of interest to researchers.

Based on the analysis seen in Fig. 4, the CiteSpace program can analyze publications for the citation burst indicator. This indicator is used to identify articles that have gained a significant number of citations in a short period of time. Citation burst can be used to identify articles with high scientific value and those that have influenced the further development of the field. Figure 5 shows the 10 publications with the highest citation burst.

Analyzing the publications with the highest citation burst, it can be seen that the highest number of citations are articles relating to the issues of Poland's energy transformation, which currently obtains most of its energy from coal [24–28]. An important aspect of these studies is the impact of renewable energy sources on Poland's energy security and the problems of implementing renewable energy sources in Poland, such as the law defining minimum distances of wind turbines from buildings. Attention was also given to the problem of implementing low-carbon technologies in rural areas [29]. This problem is particularly evident during the heating season, when many households use solid fuel stoves to heat their homes. However, due to the lack of access to the gas

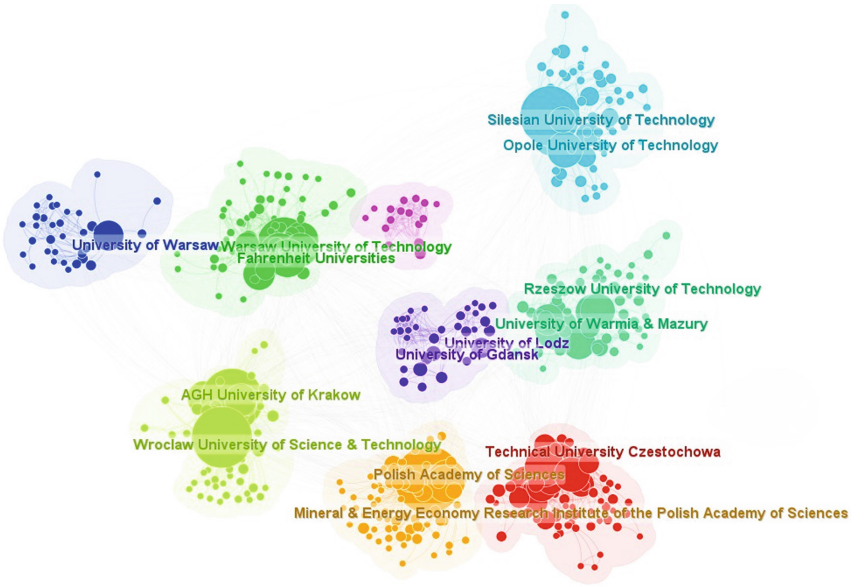

Fig. 3. Cooperation between universities.

Table 2. Number of publications and centrality by university

Institution	Number of publications	Centrality
AGH University of Krakow	412	0.08
Polish Academy of Sciences	390	0.21
Wroclaw University of Science and Technology	368	0.14
Warsaw University of Technology	343	0.13
Silesian University of Technology	339	0.06
Fahrenheit Universities	212	0.02
Lublin University of Technology	206	0.05
Technical University of Czestochowa	190	0.06
Gdansk University of Technology	188	0.02
University of Warmia and Mazury	168	0.01
Warsaw University of Life Sciences	157	0.03
Lodz University of Technology	140	0.01
Poznan University of Technology	133	0.02
Bialystok University of Technology	120	0.02
Krakow University of Technology	115	0.01

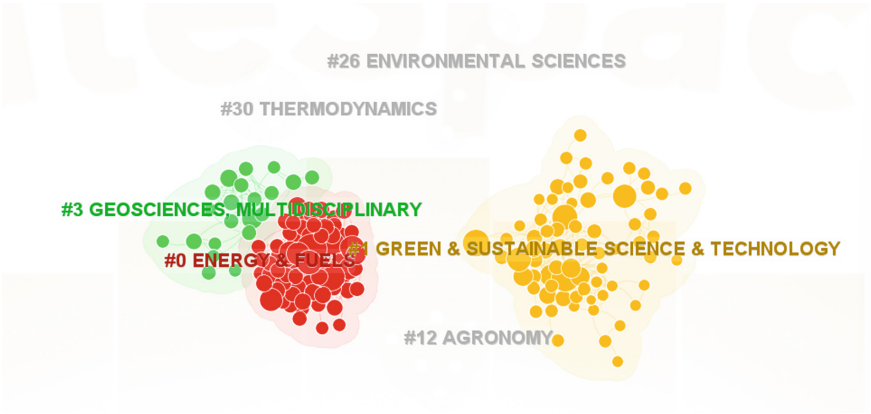

Fig. 4. Citation analysis.

References	Year	Strength	Begin	End	1993 - 2023
Budzianowski WM, 2012, RENEW SUST ENERG REV, V16, P342, DOI 10.1016/j.rser.2011.07.161, DOI	2012	4.32	2012	2017	
Szargut J, 2005, EXERGY METHOD TECHNI, V0, P0	2005	4.72	2014	2018	
Szargut J, 2002, ENERG CONVERS MANAGE, V43, P1149, DOI 10.1016/S0196-8904(02)00005-5, DOI	2002	4.92	2015	2018	
Parasyuk OV, 2012, OPT MATER, V35, P65, DOI 10.1016/j.optmat.2012.07.002, DOI	2012	4.86	2017	2018	
Piwowar A, 2019, ENERGIES, V12, P0, DOI 10.3390/en12183558, DOI	2019	5.45	2020	2021	
Marks-Bielska R, 2020, ENERGIES, V13, P0, DOI 10.3390/en13184624, DOI	2020	9.71	2021	2023	
Pietrzak MB, 2021, ENERGIES, V14, P0, DOI 10.3390/en14082046, DOI	2021	5.81	2021	2023	
Brauers H, 2020, ENERG POLICY, V144, P0, DOI 10.1016/j.enpol.2020.111621, DOI	2020	5.04	2021	2023	
Gielen D, 2019, ENERGY STRATEG REV, V24, P38, DOI 10.1016/j.esr.2019.01.006, DOI	2019	4.78	2021	2023	
Owusu PA, 2016, COGENT ENG, V3, P0, DOI 10.1080/23311916.2016.1167990, DOI	2016	4.53	2021	2023	

Fig. 5. Top 10 references with the strongest citation burst.

grid and the costliness of installing heating systems based on renewable energy sources, rural residents continue to use old and environmentally unfriendly solutions.

2.2 Bibliometric Analysis for Slovakia

Figure 5 shows the analysis in terms of authors' affiliations performed for publications from Slovakia (Fig. 6).

Table 3 shows the 10 institutes with the highest number of publications and their corresponding centrality coefficient. The analysis shows that the largest number of publications on renewable energy sources is published by scientists from the Technical University of Košice. Based on the centrality coefficient, it can be concluded that the highest number of citations and the greatest influence on other scientists are characterized by the works of scientists from the Slovak Academy of Sciences.

Figure 7 shows an analysis of citations by the main areas of interest for scientists from Slovakia.

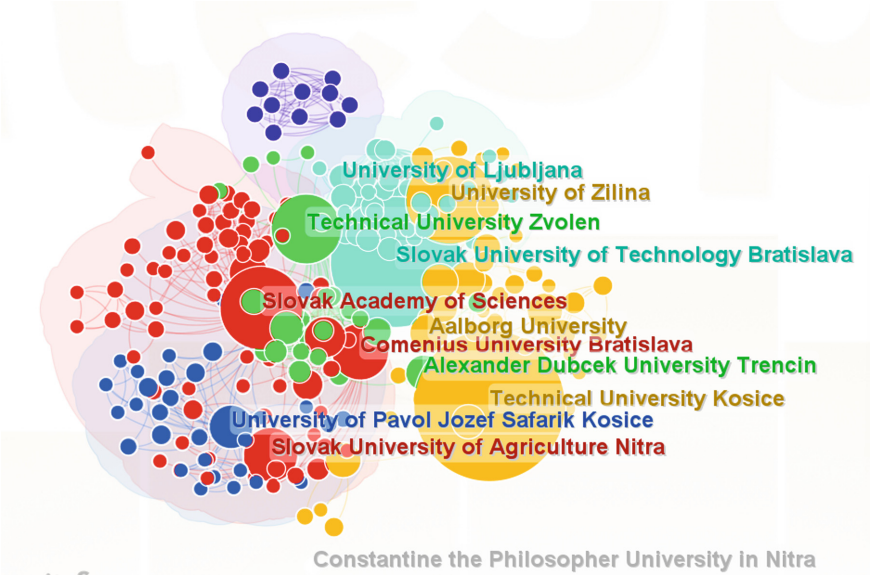

Fig. 6. Cooperation between universities.

Table 3. Number of publications and centrality by university

Institution	Number of publications	Centrality
Technical University of Kosice	323	0.22
Slovak University of Technology Bratislava	239	0.20
University of Zilina	103	0.08
Slovak Academy of Sciences	94	0.57
Technical University of Zvolen	62	0.20
Comenius University Bratislava	42	0.13
Slovak University of Agriculture Nitra	35	0.05
University of Pavol Jozef Safarik Kosice	23	0.10
University of Presov	15	0.04
University of Economics Bratislava	14	0.00

Figure 8 shows the 5 publications with the highest citation burst rate.

Analyzing the results obtained, it can be concluded that the highest number of citations in a short period of time was obtained by research on photovoltaic installations. The authors of the research present maximum power point tracking (MPPT) algorithms that will increase the efficiency of photovoltaic panels [30, 31]. The authors also discuss problems related to DC-DC converters and their impact over the performance of renewable energy systems.

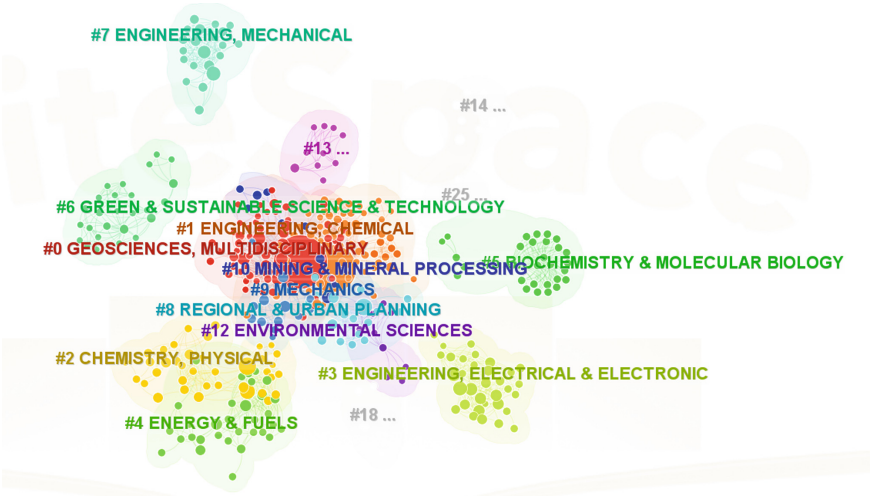

Fig. 7. Citation analysis

References	Year	Strength	Begin	End	1993 - 2023
Sanjeevikumar P, 2015, PROC IEEE INT SYMP, V0, PP214, DOI 10.1109/ISIE.2015.7281471, DOI	2015	5.82	2017	2018	
Kuric I, 2021, PROCESSES, V9, P0, DOI 10.3390/pr9050843, DOI	2021	3.58	2022	2023	
Jain S, 2016, ENG SCI TECHNOL, V19, P1771, DOI 10.1016/j.jestch.2016.07.008, DOI	2016	3.56	2018	2018	
Padmanaban S, 2017, INT J COMPUT INT SYS, V10, P140, DOI 10.2991/ijcis.2017.10.1.10, DOI	2017	3.52	2017	2017	
Blaabjerg F., 2016, J ELECT POWER COMPON, V0, P1	2016	3.52	2017	2017	

Fig. 8. Top 5 references with the strongest citation burst.

3 Conclusion

The article presents a bibliometric analysis of research on renewable energy sources in Poland and Slovakia. Thanks to the use of programs such as CiteSpace, it is possible to identify the scientific centers that constitute the most important links in research on renewable energy sources. The analysis shows that in Poland and Slovakia, the key centers in terms of innovation and number of citations are the Polish and Slovak Academy of Sciences. On the other hand, the number of publications in a given field largely depends on the size of the academic center and the number of scientists working in them, and does not indicate the innovativeness of a given scientific center.

Analyzing specific publications and links between them, it can be concluded that in the case of Poland, publications on Poland's energy transformation have the highest number of citations. Currently, most of Poland's energy is obtained from coal, and the use of renewable energy sources is critical to Poland's energy security. One of the main problems is the implementation of renewable energy sources, including the problem of minimum distances of wind turbines from buildings, as specified in the law. In addition, the problem of implementing low-carbon technologies in rural areas was also studied.

This analysis provides a better understanding of the problems of energy transition in Poland and can help develop effective solutions for future generations. In the case of Slovakia, the most cited publications relate to increasing the efficiency of photovoltaic installations through improved hardware, such as DC-DC converters. However, there is still a need for further research in certain areas, such as energy storage, smart grid technologies, and the use of renewable energy in transport.

The results of the bibliometric analysis can guide researchers and investors who make decisions about the direction of renewable energy research and investment. The analysis can also be used to assess the performance and effectiveness of scientific activities, which is important for making decisions related to their funding and assessing their impact on society.

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