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Publication Activity of Public Higher Education Institutions in Poland Corresponding to the Idea of Sustainable Energy Development – Results of a Cluster Analysis

ABSTRACT

Objective: The aim of the article is to present the involvement of public Higher Education Institutions in Poland in popularizing the idea of sustainable development within the framework of their publishing activities.

Methodology: In this study, agglomerative clustering approach, which is a representative of the hierarchical method, was used. The distance between selected public Higher Education Institutions in Poland was determined based on the Squared Euclidean Distance. In turn, to estimate the distance between clusters, the Ward method was used. The study used three parameters, constructed from data taken from *SciVal*: (1) total number of publications, (2) citation count, and (3) field-weighted citation impact.

Findings: Three groups of Polish public HEIs were distinguished as a result of the cluster analysis that was performed (based on: the total number of publications, the citation count, and the field-weighted citation impact). The most publication-productive were seven technical universities, i.e., Warsaw University of Technology, Gdansk University of Technology, Silesian University of Technology, AGH University of Science and Technology, Lodz University of Technology, Poznan University of Technology, and Wroclaw University of Science and Technology. The publications prepared by the employees of the universities of technology were also characterized by the highest number of citations.

Value Added: This article is one of the first to present (in quantitative terms) the involvement of universities in popularizing sustainable energy development concept. The methodology used in it can be applied to the other Sustainable Development Goals.

Recommendations: Given the increasing importance of the concept of sustainability in the functioning of universities, it seems necessary to create tools to measure the degree of their involvement in popularizing this idea. Among other things, universities are obliged to share their knowledge in this area. Bibliometric data provided by the *SciVal* system may be helpful in this regard. It is necessary to conduct research taking into account both domestic and foreign universities.

Key words: higher education institution, sustainable development, sustainable energy development, sustainable university, bibliometric analysis, cluster analysis

JEL codes: I21, I25, Q01

Introduction

In recent years, there has been a growing interest among policy-makers and academics in the concept of sustainable development (SD), including sustainable energy development (SED) (see: Lin, 1998; Vera et al., 2005; Chen et al., 2022; Łukasiewicz et al., 2022; Bryl & Supino, 2022; Gross-Gołacka et al., 2023). A large number of organizations or institutions are committed to the goals of sustainable development – SDGs. This even applies to Higher Education Institutions (HEIs). This is why the concept of a "sustainable university" has been around for more than two decades.

For Velazquez et al. (2006, p. 812) a sustainable university is a "HEIs that ad-dresses, involves and promotes, on a regional or a global level, the minimization of negative environmental, economic, societal, and health effects generated in the use of their resources in order to fulfil its functions of teaching, research, outreach and partnership, and stewardship in ways to help society make the transition to sustainable life-styles". Of course, sustainability initiatives at universities are supported by a number of key players in different settings and with different backgrounds such as: engineers, economists, environmentalists, or lawyers. Calder and Clugston (2003) contend that a sustainable HEI: (1) incorporates commitment to SD into its mission and academic goals; (2) integrates the concept of sustainability into teaching and research; (3) promotes support services for students; (4) encourages students to think critically about environmental issues; (5) promotes sustainable methods that minimize the ecological impact; and (6) creates local and international partnerships to enhance sustainability. In particular, it seems important to popularize the SDGs in publications prepared by academic staff and other persons carrying out and participating in teaching or research activities. In light of the current energy crisis, a commitment to the 7th SDG ("Affordable and Clean Energy") or SED seems particularly relevant.

The authors' research showed that the papers published so far have focused on the theoretical aspects of SD in HEIs' activities and on the presentation of solutions applied at the level of individual HEIs (see: Agbedahin, 2019; Amaral et al., 2015). However, two main research gaps emerge from the authors' literature review:

- Research gap 1 (RG1). There is a lack of research on the engagement of HEIs in Poland in promoting the SDGs, in particular Goal 7 "Affordable and Clean Energy".
- Research gap 2 (RG2). There is a lack of quantitative research (using bibliometric data) on the engagement of HEIs in promoting the SDGs.

That is why the main aim of this article is to present the involvement of public HEIs in Poland in popularizing the idea of SED within the framework of their publishing activities. In order to realize this aim, a set of the following research tasks was established: (1) to conduct a review of Polish and foreign literature on the concept of SD, SED, and the sustainable university; (2) to conduct a cluster analysis on the basis of the publication results achieved by selected HEIs in Poland in relation to the 7th SDG (the total number of publications, the citation count, and the field-weighted citation impact); (3) to characterize the identified clusters of HEIs in Poland and to identify the papers which were marked by the highest field-weighted citation impact.

The remainder of the paper is structured as follows. The first section, constituting the Introduction, presents a justification for the selection of the study subject, the main aim, and research tasks. The next one is a review of the literature on the concepts of SD, SED, and the sustainable university. Section three provides information on the materials and adopted research methods. The fourth part presents the results of the conducted analyses. The final part of the article comprises concluding remarks together with the presentation of limitations of this study, while also suggesting proposals for further directions of research on the subject.

Literature review

The concept of sustainability originated initially in forestry and implied that one should not harvest from forests what exceeds their productivity from new growth (Kuhlman & Farrington, 2010). It can also be stated that SD "meets the needs of

the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 15). Sustainability is a normative phenomenon concerning the way in which people should assess and make judgements in relation to the environment and the way in which they are responsible for protecting it now and in the future (Baumgartner & Quaas, 2010).

The SDGs are a roadmap for transforming and reshaping the world in which the needs of the present generation can be met in a sustainable manner, respecting the environment and taking into account the needs of future generations. The process of setting new SDGs was launched at the *UN Conference on Sustainable Development* in June 2012 (Rydz-Żbikowska, 2022). The new SDGs were agreed upon in almost three years of multilateral negotiations with governments, the private sector, academia, and civil society. Their framework goes far beyond the previously implemented *Millennium Development Goals* (MDS), adopted in 2000. The 2030 Agenda encompasses[1] five basic principles: universality (applicable to all countries), leaving no one behind (applicable to all people, regardless of status and location), interconnectedness and indivisibility (it must be implemented as a whole), inclusiveness (every contribution is important), and multi-stakeholder partnerships (to support implementation) (Mittelmeier, 2021). The *Open Working Group* – the platform established for this task – has defined 17 SDGs and 169 related tasks that reflect the three dimensions of SD: economic, social, and environmental. Each of these dimensions has performed an important role in innovation, financing, and global development efforts in recent years. In the field of economic development, innovative activities, the development of the knowledge economy, and the digitization, robotization of business processes have become some of the main variables for increasing competitiveness and further market and business development (Păunescu, 2013).

The assumption is that pursuing the goals requires being proactive and maintaining progress simultaneously at these three levels in an integrated manner. The adoption of the *2030 Agenda for Sustainable Development* and its goals

1 Adopted by the UN, the document "Transforming our world: the 2030 Agenda for Sustainable Development" is an agenda of unprecedented scope and importance, defining a model for SD at the global level.

reflects the ambition of countries to direct their efforts, strategies, and policies toward a better and more sustainable future (Aleksieva-Petrova et al., 2022). By adopting the SDGs, all UN members agreed to pursue this agenda covering all three dimensions of SD without exception (Çağlar & Gürler, 2022). The SDGs indicate which major problems in the world today should be addressed and are expected to result in: the absence of poverty (SDG 1), the eradication of hunger (SDG 2), ensuring good health and well-being (SDG 3), ensuring quality education (SDG 4), ensuring gender equality (SDG 5), ensuring clean water and good sanitation (SDG 6), ensuring affordable and clean energy (SDG 7), ensuring opportunities for decent work and economic growth (SDG 8), ensuring the development of industrial innovation and infrastructure (SDG 9), reducing inequalities (SDG 10), creating sustainable cities and communities (SDG 11), achieving sustainable consumption and production (SDG 12), climate action (SDG 13), ensuring sustainable use of oceans, seas, and marine resources (SDG 14), protecting and restoring terrestrial ecosystems (SDG 15), promoting peace, justice and strong institutions (SDG 16) and partnerships for the goals (SDG 17) (Mittelmeier, 2021). The first six SDGs reinforce and extend specific targets from the MDS. In addition, goals 7–10 broaden the scope of the MDSs and identify the root causes of poverty and inequality, as well as the inter-linkages between the economic, social, and environmental pillars of sustainable development. Goals 11–15 identify human impacts on the environment and on social and economic development. The last two goals create an enabling environment for achieving sustainable development (Rydz-Żbikowska, 2022).

Energy has always performed a significant role in the economic development of the world and, at the same time, we have seen significant changes in the types of energy use. The negative effects of dependence on coal-, oil-, and gas-fired thermal power plants using fossil fuels are being felt all over the world. Therefore, a comprehensive plan to change the way energy is produced and used was needed. The SDG 7 has become a step in this direction. It aims to reduce over-reliance on fossil fuels, bring renewable energy (solar, wind, geothermal, small hydro, etc.) into the mainstream, work to develop technologies that could enable this change, and ensure the production of clean energy accessible to all (Sugam et al., 2017).

Higher education can successfully create awareness of global sustainability issues, including those related to the need to transform the energy sector. Universities can provide knowledge, innovation, and solutions to support this goal, addressing challenges that require new ways of doing things (Fleacă et al., 2018). In addition, universities can also support the development of professional knowledge, capacity building, and motivation of future leaders, decision-makers, innovators, entrepreneurs, and ordinary citizens, whose actions and decisions will contribute to the achievement of the SDGs, including SDG 7. *Times Higher Education Impact Rankings* show the work of universities as key actors in the pursuit of SD (Hess & Collins, 2018; Žalėnienė & Pereira, 2021). Their actions contribute to the emergence of more sustainable businesses, communities, and whole societies, which, among other things, will be able to obtain the energy necessary for economic development and, at the same time, environmental degradation will be halted (Hansen et al., 2021). Hence, the concept of a sustainable university has been in the literature for more than two decades.

Wawrak (2015) defines university sustainability as a coherent, integrated, multi-directional, pro-quality way of managing the resources of a higher education institution that removes everything that blocks its development and comprehensively introduces what supports it, so that the university is never dismantled and continues to dynamically increase its scientific, research, educational, and advisory potential, serving to increase the quality of life of the academic community and the population of its country, Europe and the world. A sustainable university is both an institution where one learns to think about current events at different time scales and the impact humanity has on the environment, but it is also a place where young people learn about models of good behavior and can experience a sustainable lifestyle first-hand. The task of a sustainable university is to prepare wards to live sustainably through ethos, teaching, and the practical application of sustainable principles (Dyrtkowski, 2013). A sustainable university is one that enables students to understand environmental degradation, inspires them to adopt sustainable behaviors and increases awareness of social inequalities. As Pietrzak (2022) points out, a third-generation university is an entrepreneurial university, i.e. one that is responsible for its socio-economic environment and adheres to SD guidelines. Educational institutions, including universities,

perform a huge role in shaping and achieving the SDGs. The main role of universities is: (a) education and training, (b) research and innovation, (c) knowledge transfer, and (d) governance (Lorek, 2013). The implementation of SDGs in academic institutions should be comprehensive. As indicated by Calder and Clugston (2003), Pietrzak (2022), a sustainable university: (1) incorporates this commitment in its mission and academic goals; (2) integrates the concept of sustainability into teaching and research; (3) promotes student support services; (4) encourages students to think critically about environmental issues; (5) promotes sustainable methods that minimize environmental impact; and (6) creates local and international partnerships to enhance sustainability. In terms of education and training, this refers to the inclusion of sustainability subjects in the education plan, it also refers to high quality value-based education and the implementation of integrated sustainability curricula in all education and training programs. In terms of education, multidisciplinary and intercultural training of students and staff for SD, and creative engagement of students is important. Universities contribute significantly to sustainable economic development by equipping their graduates and young researchers with the skills and knowledge necessary to enter the labor market; stimulate entrepreneurship through the creation of spin-offs and start-ups; and improve competitiveness through technology transfer agreements. Universities drive development, reduce inequalities through education, promote intercultural cooperation, social inclusion, volunteering, work and alliances with NGOs and other institutions at local, national, and international levels. Universities should add the sustainability issues to their curricula; e.g., Lorek (2013) points out that universities of economics should introduce: 1) specialized courses dealing with SD or ecological economics, where graduates will gain interdisciplinary knowledge (technical, natural, and social) and will be leaders of SD at different levels: both in local government, public institutions, and enterprises; 2) as obligatory subjects, e.g., introduction of ecological economics, basics of SD, bioeconomics, ecology, etc.; 3) integrate sustainability-related content into the teaching of core subjects, such as e.g.: micro- and macroeconomics, management, economic policy, public finance.

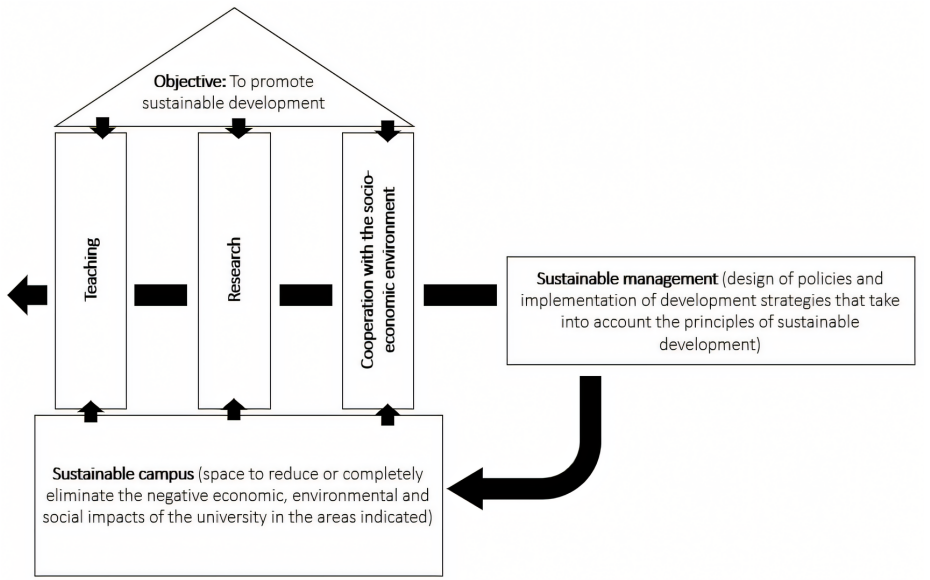
A key element of universities' missions is research and innovation. Universities should be pioneers in creating research for SD by promoting multidisciplinary

and cross-cutting research. It is particularly important to introduce science, technology, and innovation policies geared toward sustainability, including energy. Another important aspect of a sustainable university is knowledge transfer and knowledge sharing. Knowledge transfer is the driving force to achieve SDGs. Through innovative research and its dissemination, universities become key co-creators of proven, effective solutions and good practice in all areas of the SDGs. It is important to disseminate research and innovation not only locally but on a national and international scale. As Pietrzak (2022) points out, sustainable universities should use modern communication channels, such as social media to promote their involvement in SD. This allows them to share information with a wider audience, among others: students, staff, faculty members, non-community residents, campus administration and alumni leaders, and the local and national, and even international community.

University governance is a particularly important aspect of sustainable management. Universities, in order to mobilize other actors around the SDGs, should be examples of effective institutional governance by improving their functioning. In this way, they will become examples of good practice and promoters of change in their environment. In terms of governance, the activities of universities can refer to the creation of eco-campuses (Harashina, 2022), the implementation of SDGs in everyday practice, e.g., by saving energy and water, introducing waste recycling, green transport. An example of management change is Wageningen University, where a mobility policy has been adopted with three key elements: 1) travelling less; 2) switching to sustainable modes of transport (encouraging cycling); and 3) efficient, clean transport (using public transport and discouraging the use of fossil fuels for business travel and commuting) (Luttik & Maters, 2022). As indicated by Wiwoho et. al. (2021), since 2013, Universitas Sebelas Maret has continuously committed to the implementation of a green campus in order to achieve better indicators in: energy, waste, water, transport, and education. The area of green space is being increased, renewable energy elements are being introduced (lithium, solar cells, and windmills), motor vehicle use is being reduced (resulting in lower carbon emissions), paper and ink consumption is being reduced.

A graphical interpretation of the term “sustainable university” is shown in Figure 1.

Figure 1. Graphic interpretation of the term "sustainable university"



Source: Authors' elaboration.

Thus, this article is only concerned with one of the pillars of the "sustainable university", i.e., publishing activities. Therefore, the research results presented in the following part of the paper do not show the full scale of what HEIs can do for SD, and in this case SED.

Materials and methods

Objects for this study were selected based on purposive sampling. They were public HEIs in Poland, for which necessary data were available (availability of data in the *SciVal* system). Among them, one can distinguish: 18 universities, 18 universities of technology, 5 universities of economics, 5 universities of pedagogy, 6 universities of agriculture/life sciences, 6 universities of physical education. Thus, the population sample consisted of 58 out of the 59 Polish public HEIs.

Christian Theological Academy in Warsaw was not included in the research sample (because of the aforementioned lack of data). Thus, all non-public universities, which dominate the structure of HEIs in Poland, were excluded from the survey.

In selecting the diagnostic parameters, the authors were guided by their availability and validity. The study conducted took into account the publication achievements of HEIs between 2017–2022. The choice of time horizon was dictated by the availability of data. Data for 2023 were not available as of the date of completion of the article. Three parameters were used in the study:

- *X1* – the total number of publications (from 2017–2022) corresponding[2] to the 7th SDG ("Affordable and Clean Energy") or SED;
- *X2* – the total citation count of publications (from 2017–2022) corresponding to the 7th SDG ("Affordable and Clean Energy") or SED;
- *X3* – the total field-weighted citation impact of publications (from 2017–2022) corresponding to the 7th SDG ("Affordable and Clean Energy") or SED.

It should be borne in mind that the parameters used are bibliometric in nature. All were obtained from the *SciVal* system. It should be noted that they are stimulants. Therefore, the higher the value, the better.

The total number of publications indicates the prolificacy of an university: how many publications of this entity have been indexed in *Scopus*? The citation count indicates the total citation impact of an university: how many citations have this entity's publications received (citations from articles indexed in the Scopus database regardless of the affiliation of the authors)? The field-weighted citation impact indicates how the number of citations received by an university's publications compares with the average number of citations received by all other similar publications in the data universe. In other words, how do the citations received by this university's publications compare with the world average? The field-weighted citation impact of 1.00 indicates that the university's publications

2 The study included all publications indexed in the Scopus database, which in their titles, abstracts, or keywords contained phrases that fit into the 7th SDG. These phrases were defined at the *SciVal* level.

have been cited exactly as would be expected based on the global average for similar publications (the field-weighted citation impact of "world", or the entire *Scopus* database, is 1.00.). The field-weighted citation impact of more than 1.00 indicates that the university's publications have been cited more than would be expected based on the global average for similar publications, e.g., 2.50 means 150% more than the world average. On the other hand, the field-weighted citation impact of less than 1.00 indicates that the university's publications have been cited less than would be expected based on the global average for similar publications; e.g. 0.75, means 25% less than the world average.

In order to assess the selected parameters, a Pearson correlation matrix for these parameters was established (Table 1). An excessively high correlation between parameters may indicate multicollinearity. For this reason, the threshold for the correlation coefficient was set at (r* = 0.9) (Strzała & Przechlewski, 1994). Due to the low values of coefficients in this study, no variable was eliminated.

To group the HEI's in terms of their publication achievements, the authors used the agglomerative clustering approach, which is a representative of the hierarchical method. Agglomerative approach is a bottom-up approach. In this approach, data points set clusters as combining with each other (Eden & Tommy, 2004).

Table 1. A Pearson correlation matrix for the investigated parameters

Variable	*X1*	*X2*	*X3*
X1	1.00	0,76*	0.05
X2	0.76*	1.00	0.11
X3	0.05	0.11	1.00

* Correlation coefficients are significant with $p < 0.05$.

Source: Authors' elaboration.

The distance between the objects (here: selected public HEIs in Poland) was determined based on the Squared Euclidean Distance. This distance method uses the Pythagorean theorem. And it is the distance calculation that is most often used in the process of machine learning (Alamri et al., 2016). The Euclidean distance is squared to assign more weight to objects that are further away. What is

important, clustering with the Squared Euclidean Distance metric is faster than clustering with the regular Euclidean distance.

In turn, to estimate the distance between clusters, the Ward method was used. This method differs from the others (such as: single linkage method, complete linkage method), as it uses the analysis of variance approach, i.e., it attempts minimization of the sum of squares of deviations within the clusters. The Ward method is considered to be efficient, although its application leads to the formation of small-sized clusters (Stanisz, 2007). This method is said to be the most suitable method for quantitative variables. The analysis provided a dendrogram, constituting a graphical interpretation of obtained results. The results suggest that these methods are useful in typical examples and real data sets.

It needs to be stressed here that the parameters (*X1*, *X2*, *X3*) included in this study were expressed in different units. For this reason, prior to their analysis, they were subjected to a normalization procedure. It results from the analysis of literature on the subject that the best formal properties among the normalization methods are found for zero unitization (Kukuła, 2012). Using this method, the normalized values from the range of <0;1> were obtained. In this case, the value of 1.00 was given for the HEI, in which case, *X1*, *X2*, *X3*, were the highest.

All calculations were made with the use of the *MS Office 365* package and *STA-TISTICA* software.

Findings and discussion

The most obvious and traditional way that HEIs might help to deliver the SDGs is by creating research in relevant topics and preparing articles based on them. Of course, this is only one pillar of the functioning of sustainable universities. Obviously, HEIs with a publication achievement may be less adept at, e.g., reducing their negative impact on the environment. Thus, the results presented here relate only to a fragment of the activities that are part of the sustainable university concept.

It is worth noting at this point that in 2020 *Elsevier*, through *Science-Metrix*, developed a new approach to mapping publications to the SDGs. Taking customer feedback into account, they greatly enhanced the number of search terms used to define each SDG. Those queries were then complemented by a machine learning model (Pietrzak, 2022). For example, articles that had the following word phrases in their titles, abstracts, or keywords were assigned to the 7th SDG ("Affordable and Clean Energy"): "geotherm", "bioaccumulation", "national renewable energy", "clean energy", "solar", "vegetable oil fuel", "biomass gasifier", "hydro generator", "hydro plants", "tidal energy re-source".

The further part of this study presents the results of a cluster analysis. In the first step of this analysis, the three parameters (*X1*, *X2*, *X3*) were subjected to zero unitization. On their basis, the following conclusions may be drawn:

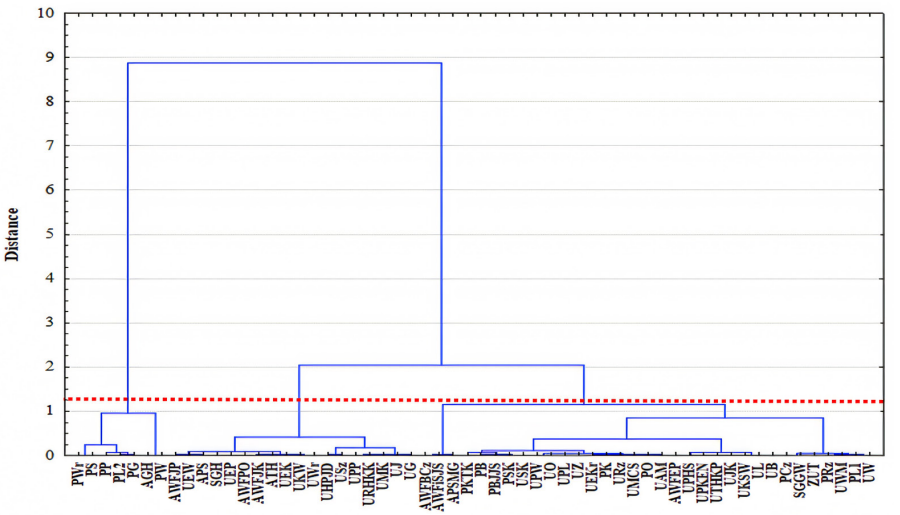
- The largest number of publications (1,188 publications) corresponding to the 7th SDG in 2017–2022 was created at the Warsaw University of Technology (PW).
- The most cited papers (10,921 citations) between 2017 and 2022 corresponding to the 7th SDG were those prepared by researchers at the AGH University of Science and Technology (AGH).
- The University of Szczecin (USz) had the highest field-weighted citation impact for the 7th SDG in the period 2017–2022. Its value was 2.10.
- The HEI that achieved the lowest values in all three indicators was the Maria Grzegorzewska University (APSMG).

The aim of the conducted cluster analysis was to classify selected Polish HEIs into groups that differ in terms of their publication achievements corresponding to the 7th SDG. The distinguished groups should meet the criteria of internal cohesion, i.e., homogeneity and external isolation (heterogeneity). Figure 2 presents a dendrogram showing the obtained hierarchy of clusters. The horizontal axis represents countries constituting the study sample, while the vertical axis indicates the distance of the linkage, in this case the SED.

In order to determine the optimal number of clusters, the graph of agglomeration was used, which presents the distance between clusters at the time of their

grouping (Figure 3). The cut-off point was established at the point of a sudden increase in the distance of linkage. In the analyzed case, it was between step 56 and 57. Their ordinate corresponds to the distance between linkages amounting to approx. 1.40. For this reason, it was possible to distinguish three clusters (see the broken red line in Figures 2 and 3).

Figure 2. The dendrogram of hierarchical clustering using Ward's method for selected HEIs from Poland

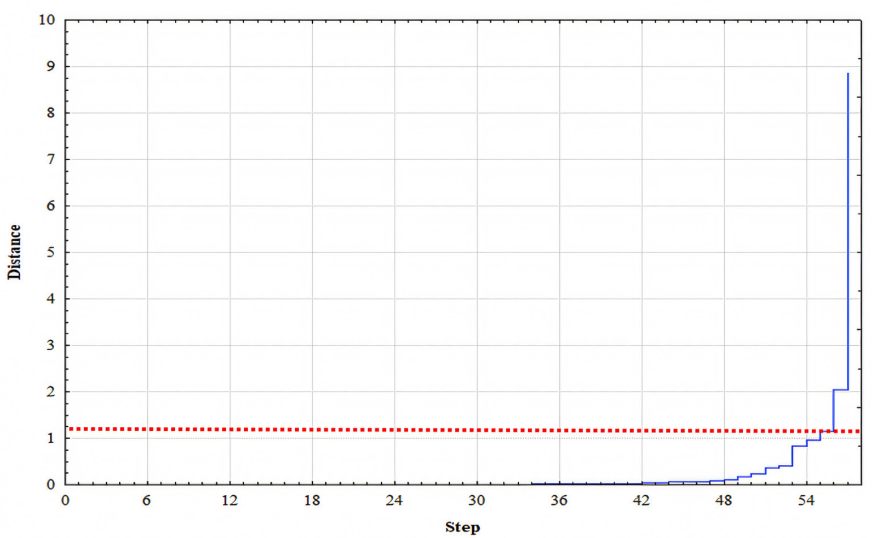


Where: University of Warsaw – UW, University of Bialystok – UB, University of Gdansk – UG, Adam Mickiewicz University in Poznan – UAM, Jagiellonian University in Krakow – UJ, University of Lodz – UL, Maria Curie-Sklodowska University – UMCS, Nicolaus Copernicus University in Torun – UMK, University of Opole – UO, University of Szczecin – USz, University of Silesia in Katowice – USK, University of Rzeszow – URz, University of Warmia and Mazury in Olsztyn – UWM, University of Wroclaw – UWr, Cardinal Stefan Wyszynski University – UKSW, University of Zielona Gora – UZ, Kazimierz Wielki University – UKW, Jan Kochanowski University in Kielce – UJK, West Pomeranian University of Technology – ZUT, Warsaw University of Technology – PW, Bialystok University of Technology – PB, University of Bielsko-Biala – ATH, Czestochowa University of Technology – PCz, Gdansk University of Technology – PG, Silesian University of Technology – PS, Kielce University of Technology – PSK, Koszalin University of Technology – PK, Krakow University of Technology – PKTK, AGH University of Science and Technology – AGH, Lublin University of Technology – PL1,

Lodz University of Technology – PL2, Opole University of Technology – PO, Poznan University of Technology – PP, Radom University of Technology – UTHKP, Rzeszow University of Technology – PRz, Wroclaw University of Science and Technology – PWr, University of Economics in Katowice – UEK, Krakow University of Economics – UEKr, Poznan University of Economics and Business – UEP, SGH Warsaw School of Economics – SGH, Wroclaw University of Economics and Business – UEW, Maria Grzegorzewska University – APSMG, Jan Dlugosz University in Czestochowa – UHPJD, Pedagogical University of Krakow – UPKEN, Pomeranian University in Slupsk – APS, Siedlce University of Natural Sciences and Humanities – UPHS, Warsaw University of Life Sciences – SGGW, University of Agriculture in Krakow – URHKK, University of Life Sciences in Lublin – UPL, Poznan University of Life Sciences – UPP, Wroclaw University of Environmental and Life Sciences – UPW, Bydgoszcz University of Science and Technology – PBJJS, Gdansk University of Physical Education and Sport – AWFiSJS, The Jerzy Kukuczka Academy of Physical Education in Katowice – AWFJK, University of Physical Education in Krakow – AWFBCz, University School of Physical Education in Poznan – AWFEP, Jozef Pilsudski University of Physical Education in Warsaw – AWFJP, University School of Physical Education in Wroclaw-AWFPO.

Source: Authors' elaboration.

Figure 3. A graph of the distance of linkage in relation to linkage stages



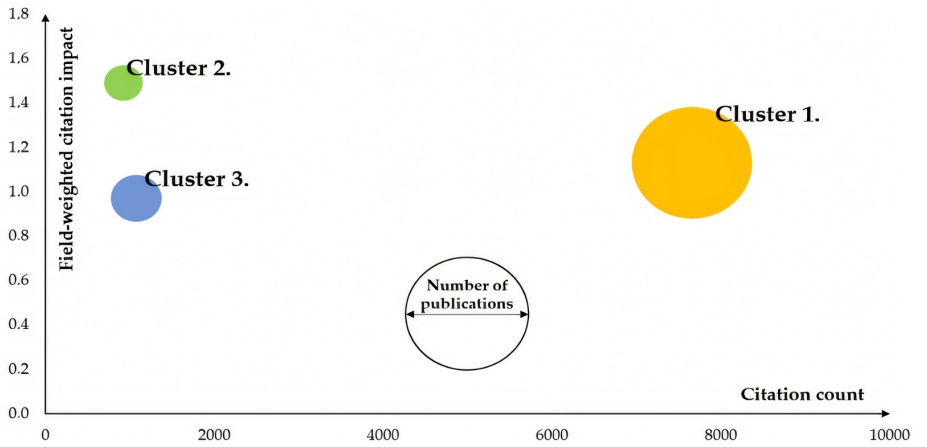
Source: Authors' elaboration.

Cluster 1 included seven HEIs. All of them belong to the group of technical universities. Cluster 2, on the other hand, consisted of 19 HEIs. Among them were: 6 universities, 1 university of technology, 4 universities of economics, 2 universities of pedagogy, 2 universities of life sciences, and 4 universities of physical education. Finally, cluster 3 was formed by the largest number of universities. The 32 HEIs included: 12 universities, 10 universities of technology, 1 university of economics, 3 universities of pedagogy, 4 universities of life sciences, and 2 universities of physical education. The average values of all three indicators were calculated for each cluster and used to prepare Figure 4. The horizontal axis shows the average number of citations from 2017 to 2022, the vertical axis the average value of the field-weighted citation impact from 2017 to 2022. The diameter of the circle, in turn, shows the average number of publications from 2017 to 2022.

It is noteworthy that the HEIs included in cluster 1 were the most publication-productive. In other words, although this cluster contained the smallest number of HEIs, their scientific staff prepared, on average, the largest number of papers corresponding to the 7th SDG (826 publications) between 2017 and 2022. In addition, this cluster stands out for having the highest average number of citations (7,658 citations). In contrast, the average value of the field-weighted citation impact of publications was 1.13, which indicates that the articles have

been cited more (13%) than would be expected based on the global average for similar publications.

Figure 4. Graphical characterization of clusters by mean values of parameters



Source: Authors' elaboration.

HEIs that fell into cluster 2 were much less productive in terms of publications. The average number of papers between 2017 and 2022 stood at 81 articles. Nevertheless, they received quite a lot of attention as evidenced by the high value of the field-weighted citation impact of publications (1.49 on average).

Finally, cluster 3 was formed by HEIs that showed an average publication productivity (average 148 articles per HEI), an average number of citations (1.075 citations per HEI), and the lowest average value of the field-weighted citation impact (0.97 on average).

The involvement of public HEIs in Poland in promoting the 7th SDG through their publication activities is varied. Among them, it is possible to identify quantitative leaders (a significant number of publications) and those universities whose papers are appreciated by other researchers (high citation count and high field-weighted citation impact). It was not possible to distinguish a cluster, whose HEIs would reach on average the highest values in all analyzed indicators.

Based on the results obtained, it can be concluded that the Polish public technical universities are more involved in popularizing the concept of SED

This is, of course, due to their specialization (i.e. the research they conduct as well as the teaching they deliver). In this respect, it is not surprising that universities with other profiles, such as physical education academies, achieve worse results in this area. Other authors (see: Ferrer-Balas et al., 2008; Jorge et al., 2015) have already pointed out that the profile of a university can determine the degree of its commitment to the idea of SD. Therefore, it is worth emphasizing that HEIs that do not achieve outstanding results in their publication activities corresponding to the 7th SDG do not have impressive results in the other SDGs.

It is worth pointing out that the use of bibliometric data to show the degree of involvement of HEIs in popularizing the idea of SED, more broadly SD, has been the subject of few scientific studies. For example, Pietrzak (2022) showed that the highest publication productivity (number of articles per number of academic staff) in 2021 within the individual SDGs was demonstrated by the following universities: Warsaw University, Warsaw University of Life Sciences, Jagiellonian University in Krakow, Silesian University of Technology, AGH University of Science and Technology, and Krakow University of Technology, and University of Gdansk WULS, JU, SUT, AGH, KUT3, and UG. He also stated that universities of technology had the highest publication productivity for two goals: SDG7 and SDG9. In this respect, the results obtained by the authors are coherent.

Conclusions, limitations and further research

Nowadays, HEIs are increasingly taking on the responsibility of promoting the concept of SD. They can do this by, among other things, integrating the concept of sustainability into their teaching or research process. It seems that the easiest way to promote SGD is through publicity activities carried out by academics. Nevertheless, to the best of the authors' knowledge, there is a lack of studies using bibliometric data to enable cross-university comparisons.

Hence, in this paper, an attempt was made to show the engagement of selected public HEIs in Poland in promoting the 7th SDG – "Affordable and Clean Energy" (or SED) – from 2021 to 2022. The following conclusions were formulated as a result of the survey:

- Three groups of Polish public HEIs were distinguished as a result of the cluster analysis that was performed (based on: the total number of publications, the citation count, and the field-weighted citation impact).
- The most publication-productive were seven technical universities, i.e. PW, PG, PS, AGH, PL2, PP, and PWr.
- The publications prepared by the employees of the universities of technology were also characterized by the highest number of citations.
- The highest value of the field-weighted citation impact of publications was achieved by the following universities: UG, UJ, UMK, USz, UWr, UKW, ATH, UEK, UEP, SGH, UEW, UHPJD, APS, URHKK, UPP, AWFJK, AWFBCz, AWFJP, AWFPO.

On the basis of the study carried out, the authors strongly believe that the two research gaps (RG1, RG2) presented in the introduction have been addressed. With this, this paper presents, for the first time, the involvement of public HEIs in Poland in promoting the 7th SDG (or SED) on the basis of publication activities. The authors did not intend to make recommendations for less productive universities (which may have a track record in promoting other SDGs). Additionally, the study used bibliometric data, making it quantitative in nature (as opposed to the qualitative studies that dominate the field). It can also be concluded that the main aim of the study has been met.

Of course, the authors are aware that the obtained results can be criticized from the point of view of the adopted research methodology. Firstly, the authors referred only to the publication activity of HEIs. As noted earlier, universities can also be involved in SD through teaching activities. These indicated aspects have been disregarded in this study. Secondly, in the theoretical part of the article, some studies (in particular books and chapters therein) that could be of importance to some scholars with regard to the described issues (but only in the area

of SED, and SD) may have been omitted. The authors, when selecting the literature, were guided by the availability and the importance of a journal, or a scientific publishing house. It is noteworthy that research into the popularization of the idea of sustainable energy development by universities has not been carried out. Thirdly, limitations of the agglomerative clustering technique should also be kept in mind. Hierarchical clustering methods do not require a prior determination of the number of clusters (which non-hierarchical methods require), but they do require a lot of computing power. Clusters are usually not created based on any theoretical basis. Instead, clusters are created randomly. Therefore, it is sometimes difficult to find a justification for the cluster structure.

The presented limitations also suggest further research directions. First of all, in the future, research should be carried out on a larger research sample (inclusion in the study also of non-public universities which, as part of their publishing activities, are engaged in popularizing the idea of SD, including SED). International comparisons are recommended in this respect (universities from different countries). In addition, it would also be interesting to see how universities support the 7th SDG in their teaching activities i.e., what is the number of subjects in which issues such as renewable energy sources are discussed, or what is the number of graduates of courses in which SED is addressed. It would also be worthwhile to indicate what determines the involvement of HEIs in the indicated activities (e.g., profile, size of university, their location or age).

The authors hope that the results presented in this article, will inspire further re-search into this issue. The engagement of universities in the promotion and implementation of the concept of SD is an extensive research issue that requires further exploration.

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