"Indicators differentiating the sustainability profiles of leading universities in the QS Sustainability Rankings"

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INDICATORS DIFFERENTIATING THE SUSTAINABILITY PROFILES OF LEADING UNIVERSITIES IN THE QS SUSTAINABILITY RANKINGS

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Abstract

Higher education plays an important role in advancing the sustainable development paradigm. The corresponding contribution of universities is measured, in particular, by the QS Sustainability Rankings, which summarizes nine comprehensive indicators for assessing various aspects of sustainability. The study aims to analyze the structure of the QS Sustainability Rankings for leading global universities and identify the indicators that most significantly distinguish the ranked profiles of these institutions. The study covered the top 30 universities in the QS World University Rankings: Sustainability 2026 (31 universities due to tied ranking scores). The Pearson coefficient showed a fairly strong pairwise relationship with the ranking score for indicators such as "Equality", "Environmental Research", "Impact of Education", and "Employability & Opportunities"; however, the typology of university profiles is more complex. Therefore, based on the principal component analysis method, the indicators most strongly associated with the variation of universities in the Ranking were identified: "Health and Wellbeing", "Knowledge Exchange", and "Environmental Sustainability". A cluster analysis showed that university profiles in the QS Sustainability Rankings vary across clusters: cluster I (17 institutions) is predominantly oriented toward strengthening social impact, cluster II (7 institutions) toward strengthening environmental impact, and cluster III (7 institutions) has a mixed orientation. Therefore, based on classification analysis, a combination of indicators ("Environmental Sustainability", "Impact of Education", "Health and Wellbeing") was identified as most strongly distinguishing the obtained clusters, that is, differentiating the ranked profiles of leading universities. Other institutions can use this to substantiate the priorities of their sustainable transformation strategy.

Keywords higher education, sustainable development, universities, QS Sustainability Rankings, indicators, correlation, principal component analysis, clustering, classification analysis

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INTRODUCTION

The transition to sustainability is one of the central issues of the twenty-first century, involving the balancing of environmental, economic, and social aspects united within a new paradigm of human progress. Higher education is a critically important force in promoting and disseminating the principles of sustainable development (Tafese & Kopp, 2025). Its role in addressing the global problems of humanity has been recognized at the UN level and enshrined in the Sustainable Development Goals (SDGs), which serve as the guiding framework for international sustainable development policy (Shu & Tian, 2024). The contribution of higher education to advancing the sustainable development paradigm is formed at the level of universities, which, in pub-

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lic understanding, are increasingly responsible for implementing the SDGs and must accordingly adapt educational programs, scientific research, and transform infrastructure within a holistic strategy of change. Sustainability is becoming an important factor not only for the image and reputation of higher education institutions, but also for the quality of their educational activities.

Only by properly implementing sustainable development principles can universities be effective in the modern sense and achieve advantages in the educational services market (Zhavoronok et al., 2024). Therefore, universities seek to increase their level of sustainable development, which gives rise to the problem of managing its components, which are assessed by special international rankings, in particular the QS Sustainability Rankings (QS TopUniversities, 2026). In view of the intensification of international competition in the field of sustainable transformation, it is necessary to deepen the analysis of the variation of global leading universities in the QS Sustainability Rankings, focusing attention on the indicators that most strongly differentiate the ranked profiles of universities. This will allow us to deepen our understanding of the typology of educational institutions' profiles and identify hidden combinations of ranking-component indicators that shape the strengths and high performance of leading universities in sustainable development. The choice of the QS Sustainability Rankings among other most authoritative rankings, such as the Times Higher Education Impact Rankings and the UI GreenMetric World University Rankings, is determined by the fact that it provides objective data and summarizes the SDGs within comprehensive indicators, the number of which is optimal for analysis.

1. LITERATURE REVIEW

The role of higher education in the transition to sustainable development is studied both at the level of countries and at the level of individual educational institutions (Tafese & Kopp, 2025; Machado & Davim, 2022). Higher education contributes to the achievement of practically all SDGs established at the UN level and forming the modern international agenda (Chankseliani & McCowan, 2021). The primary contribution of higher education to the development of the sustainability paradigm and its impact on society is realized through the activities of universities, which are becoming the main agents of change and must demonstrate leadership by example (*Žalėnienė* & Pereira, 2021). Universities are increasingly focusing on achieving the SDGs within the framework of the "third mission" – social responsibility to society. A powerful external stimulus for the active implementation of the SDGs in university strategies, among other factors, is the emergence of international rankings, in particular the QS Sustainability Ranking, which assesses compliance with certain standards and compares the achievements of institutions from different countries (Gharzeddine & Davies, 2025).

Focusing on the implementation of the SDGs, universities not only change educational programs but also make broader use of new working methods, tools, and other opportunities to ensure high-quality and accessible education through digital technologies (Zhavoronok et al., 2024). Studies of practical experience in implementing sustainability principles in higher education show that universities' role in achieving the SDGs, in addition to adapting educational programs, increasingly covers scientific research, development, and interaction with society, including government, business, and communities (Drissi et al., 2025). The leading role of universities as drivers of achieving the SDGs naturally has national specificities relating to various aspects, such as the involvement of teachers, students, and external partners. Higher education institutions are a "living laboratory" where unique combinations of factors are formed that allow the principles of sustainability to be integrated into science, education, and community life (Purcell et al., 2019). Universities are uniquely positioned to disseminate the ideas of sustainable development through the training of future leaders, partnerships with diverse social structures, and the creation and dissemination of a relevant culture among the population, making them drivers of social change (Munaro & John, 2025). This requires universities to pursue a targeted long-term policy of sustainable transformation.

Against the background of demand from governments, society, and conscious students, universities are undergoing significant institutional transformations aimed at incorporating sustainable development into their core missions (Irungu & Liu, 2024). The structure of the educational services supply chain and the agenda of scientific work are undergoing profound changes, with an emphasis on environmental responsibility (Jauhar et al., 2017). Sustainable development is being institutionalized; relevant strategies are emerging in universities, and internal and external reporting in this field is being carried out (Tullio & Rea, 2025). The implementation of the foundations of sustainable development in university activities covers various dimensions, including student engagement, changes in educational programs and curricula, the reorientation of research and development, and new benchmarks in campus management, where problems often arise due to the absence of a systemic approach and the weakness of strategy. Among other things, there is a lack of reliable indicators for assessing sustainable transformation to better understand its components and substantiate priorities (Ankareddy et al., 2025).

The integration of the foundations of sustainability, in addition to significant opportunities such as the modernization of educational programs, investment attraction, and the development of research, creates substantial challenges for universities, including a lack of funding, the complexity of long-term planning, the conservatism of curricula, and resistance to change among staff, which requires the search for new paths and solutions (Abo-Khalil, 2024). The analysis of experience confirms the need for a holistic approach to implementing the principles of sustainability in higher education, covering all dimensions of transformation: educational programs, the physical and mental health of the community, economic feasibility, social justice, and environmentally friendly transport. A prerequisite for this, as well as for overcoming complex barriers, is high-quality monitoring and assessment of the university's environmental and social outcomes (Barnett-Itzhaki et al., 2025).

The transition of universities to sustainable development is a complex multidimensional process, the course and results of which are influenced by many internal and external factors, including the level of the institution, its potential, scientific activity, reputation, and inclusion in international networks, which also gives rise to a certain variability in the strategies of different universities. Moreover, sustainable transformation is accompanied by profound changes in educational and scientific work, structure, organization of activities, and other aspects (Lim et al., 2022). This determines the need for systematized planning and special management of this process, which requires a clear understanding of the specificity, or profile, of the university and the key factors of sustainable development of other institutions. In addition to public reporting, a transparent system of internal control and performance measurement is needed (de Villiers et al., 2025).

The analysis of contemporary studies in the field of sustainability of higher education institutions demonstrates growing attention to the effectiveness of sustainable transformation (Hassan & Ahmad, 2025). At the same time, the understanding of the concept of "sustainable development performance" in higher education institutions is evolving. Therefore, the assessment of universities' environmental sustainability increasingly goes beyond campus management and requires coverage of educational programs, the learning process, scientific research, and interaction with the community, while also drawing attention to the systematization and measurement of achievements (Almutaiti & Talib, 2025). In this context, benchmarking procedures may be applied by comparing the best practices and indicators of different universities that hold leading positions (Caeiro et al., 2020).

Due to the multicomponent nature of universities' sustainable development, its assessment is also quite complex. Moreover, it is carried out, with certain differences, in two dimensions: internal, through self-assessment, and external, covering international rankings and accreditation systems (Alba-Hidalgo et al., 2018). The need to manage sustainable transformation requires systematic monitoring, covering both the external and internal environment, for example through a special system of indicators that would allow not only a comprehensive assessment of changes at the level of individual institutions, but also the comparison of the achievements of different universities (Valls-Val et al., 2024). Therefore, the assessment of the sustainable development of higher education in-

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stitutions is a major area of research, in which the main attention is concentrated on developing a comprehensive set of indicators and overcoming the difficulties of carrying out the relevant measurements. The indicator-based approach prevails; it is effective and transparent and provides broad opportunities for continuous monitoring, comparison of results, and comparison of the behavior of different institutions. An important tool for assessing university sustainability based on indicators is international rankings, which will be discussed further (Basheer et al., 2025; Justi et al., 2025).

A holistic approach is applied both to ensuring and to assessing sustainable development in universities, covering teaching, research, governance, infrastructure, and social activity. On this basis, the real contribution of a particular institution to the achievement of the SDGs is measured, which makes it possible to identify "gaps" in the strategy, allocate resources more effectively, and transform the components of sustainability (Saez de Camara et al., 2021). In implementing the holistic approach, comprehensive indices, or rankings, for assessing the results of universities' sustainable transformation can be widely used in management accounting and public reporting. In addition to management, this is critically important for engaging stakeholders, including students, teachers, and the community, and for improving the reputation of the institution (Zahid et al., 2020). In recent years, the principles of sustainable development have been increasingly integrated into systems for assessing the quality of higher education. The relevant quality criteria are connected with the general environmental, social, and governance (ESG) indicators of universities (De Oliveira et al., 2025), which is also reflected in special international rankings.

The global spread of the sustainability paradigm and the interest of universities in rapid and successful transformation stimulate international comparisons and the study of experience. Naturally, the greatest attention is paid to world-class universities. However, even these universities, while sharing common goals, demonstrate differences in priorities, in particular environmental or social aspects, which reflects different strategic visions of sustainability. This makes the relevant international comparisons more topical (Shu & Tian, 2024).

The transition to sustainable development naturally changes the assessment of university performance, in which criteria related to the level of sustainability, or "green" indicators, are expanded and influence the competitive positions of institutions. Classical university rankings, which focus mainly on scientific research and academic reputation, are supplemented by assessing achievements in sustainable development through special components or rankings such as the UI GreenMetric World University Rankings (WUR) (Burmann et al., 2021). The transformation of environmental friendliness, social responsibility, and contribution to solving the global problems of humanity into new criteria of success expands the application of special university sustainability rankings that assess precisely their contribution to achieving the SDGs (Wolhuter, 2022). This does not destroy the traditional competitive logic of higher education, but transforms it and creates a new sphere of competition in which higher education institutions compete, seeking to attract more funding and applicants (Buckner & Zhang, 2025).

The UI GreenMetric WUR historically became the first specialized international university sustainability ranking (UI GreenMetric World University Rankings, 2026), covering six comprehensive criteria and widely used in scientific research and management. In particular, the UI GreenMetric WUR is used to assess the relationship between universities' environmental activities and their academic achievements, for example by comparing its components with leading global rankings of academic performance, namely the QS WUR and the Times Higher Education WUR. This makes it possible to understand whether the implementation of sustainable development practices contributes to improving universities' academic performance and reputation or whether it remains an isolated aspect of their activities (Atici et al., 2021; Wilhelm et al., 2026). There are also more comprehensive studies of the relationships between UI GreenMetric and, simultaneously, the QS World University Rankings, Times Higher Education (THE) World University Rankings (WUR), Academic Ranking of World Universities (ARWU), and Webometrics, which makes it possible to study the interaction of sustainability rankings with the traditional system of higher education assessment in a broader context (Muñoz-Suárez et al., 2020). In addition, the UI GreenMetric WUR is used to analyze the influence of university policy on society's perception of environmental protection beyond the campus itself, allowing the situation in different countries to be compared (Puertas et al., 2023). Another area of application of the UI GreenMetric criteria and indicators is the assessment of universities' effectiveness in sustainable transformation to determine the specific features of the strategies and environmental activities of a particular educational institution (Gültekin et al., 2024). However, over a fairly long period of its existence, numerous critical reviews of the UI GreenMetric WUR have appeared, particularly concerning its assessment methodology, criteria, and indicators of campus sustainable development (Lauder et al., 2015). Although this ranking is one of the oldest and most well-known, it has a number of profound problems, for example, self-selection bias, the risk of institutional greenwashing, and methodological shortcomings, including the use of absolute indicators, the lack of transparency and "subjectivity" of weighting coefficients, the lack of data verification, and so on. This complicates the comparison of universities and makes this ranking rather an instrument of internal monitoring (Alberti et al., 2025; Boiocchi et al., 2023).

Another ranking actively used in assessing the sustainable development of universities is the Times Higher Education (THE) Impact Rankings (THE Impact Rankings, 2026). This ranking is clearly oriented toward assessing the contribution of universities to the achievement of the seventeen SDGs. Based on THE Impact Rankings data, the achievements of individual universities in attaining the SDGs are studied, identifying their strengths and weaknesses in the field of sustainable development (Ordonez-Ponce et al., 2024). At the same time, the ranking has both advantages and objective potential limitations in measuring the social and environmental impact of higher education. While providing a reliable overview of sustainable development indicators, THE Impact Rankings allows significant differences in the behavior of universities in terms of their reporting (Urbano et al., 2025). Constructive criticism of THE Impact Rankings, among other things, is connected with the subjectivity of the methodology and the lack of transparency (Kaloutsa et al., 2025). Therefore, this ranking is often used by universities themselves as a tool for marketing and prestige enhancement. Accordingly, there may be substantial differences between the data submitted by universities and real changes in relation to sustainability (Bautista-Puig et al., 2022).

The third ranking for assessing university sustainability is the QS World University Rankings: Sustainability (QS TopUniversities, 2026). This ranking is also widely used to analyze the relationship between sustainable development practices and the academic results of universities. For this purpose, its data are compared with the indicators of four leading traditional global university rankings to assess the impact of sustainability efforts on improving the academic reputation, scientific productivity, and competitiveness of institutions (Irungu & Liu, 2024). The QS Sustainability Rankings is also applied to analyze sustainability efforts directly and their impact on the positions of universities in classical global higher education rankings, including within individual countries (Sehgal et al., 2025). It should be noted that, due to its relative novelty, the QS World University Rankings: Sustainability has been studied less than the others.

In general, there is a growing significance of international rankings in assessing university sustainability, influencing institutional policy and, in particular, students' decisions regarding admission. High positions in sustainable development are regarded as a new competitive advantage, which applies in particular to world-class universities. This encourages universities to pursue more active strategies that adapt to the logic and dimensions of rankings (Leal Filho et al., 2025).

Of course, international rankings cannot sufficiently reflect the entire complexity and effectiveness of sustainable transformation. They have substantial methodological problems, including the problem of subjective and fixed weighting coefficients, the problem of data aggregation, the use of absolute indicators instead of relative ones, the problem of compensation between components, the problem of university self-reporting, and so on; natural limitations as constructed indicators, including the reduction of the complexity of the university and the process of sustainable transformation, the ignoring of national context, local con-

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ditions, and institutional diversity; and often non-transparent methodology (Kaloutsa et al., 2025; Matulová, 2023). At the same time, sustainability rankings, in particular the QS Sustainability Rankings, provide fairly high-quality operational data for international comparisons of universities, characterizing their profiles in this field.

Various mathematical methods are widely used to study the sustainable development of universities, companies, and countries as a whole. In particular, principal component analysis (PCA) is used for benchmarking OECD countries according to sustainable development indicators, including for the objective determination of the weighting coefficients, or significance, of the indicators covered by the assessment (Lamichhane et al., 2021). The suitability of PCA is also demonstrated by a study on the multidimensional assessment of the effectiveness of "green education" in universities, integrating indicators from the Times Higher Education WUR and the UI GreenMetric WUR. In addition to PCA, the author applies correlation, regression, and cluster analysis to group universities according to sustainable development indicators (Sahin, 2025). It should be emphasized that in the study of sustainable development, in particular the achievement of the SDGs, where multidimensional analysis is required, machine learning methods are used, including the combination of correlation, network, and cluster analysis, as well as PCA, which together make it possible to identify hidden patterns and relationships between different indicators of different countries (García-Rodríguez et al., 2025). In assessing the contribution of universities to sustainable development on the basis of UI GreenMetric indicators using the Data Envelopment Analysis method, cluster analysis is also used to divide institutions into four homogeneous groups for the purpose of more detailed comparison (Puertas & Marti, 2019). Clustering based on data provided, for example, by the UI GreenMetric WUR may serve as a basis for classifying universities, which complements traditional ranking approaches and also allows institutions from different countries to be compared (Perchinunno & Cazzolle, 2020).

The analysis showed that, despite growing attention to the role of universities in advancing the paradigm of sustainable development, the specific features of their variation and the typology of their profiles in international sustainability rankings, in particular in the QS Sustainability Rankings, have been studied fragmentarily. There is a need to develop new approaches for conducting parametric international comparisons of university profiles in such rankings, which will deepen the understanding of their typology and create a basis for studying the factors of effectiveness and the actual strategies of educational institutions in the field of sustainable development. For this purpose, along with common approaches such as correlation, regression, cluster analysis, PCA, and others, it is advisable to apply methods of classification data analysis.

The study aims to analyze the structure of the QS Sustainability Rankings for leading global universities and to identify, among its components, those indicators that most strongly differentiate the ranked profiles of these institutions.

2. METHODS

For the study, the QS Sustainability Rankings (QS TopUniversities, 2026) were selected from the three leading global university sustainability rankings for several reasons. First of all, this ranking is newer and less researched compared with UI GreenMetric and THE Impact Rankings, without taking into account the broader criticism of these two rankings. Compared with UI GreenMetric, the QS Sustainability Rankings includes more comprehensive indicators: nine in the QS Sustainability Rankings and six in UI GreenMetric, which are measured quantitatively. Based on objective data, the QS Sustainability Rankings assess a university as a global actor that influences the economy, society, and world science. UI GreenMetric focuses on the university's internal infrastructure and on assessing the campus's compliance with sustainability requirements using information provided by the institutions themselves.

Compared with THE Impact Rankings, the QS Sustainability Rankings has fewer components, while it also assesses contributions to all 17 SDGs, summarising them into 9 components, which provides advantages for analysis. The QS

Sustainability Rankings compares universities according to the same parameters and a clear methodology, whereas THE Impact Rankings allows universities to choose which SDGs to emphasize when submitting reports for ranking. In addition, the QS Sustainability Rankings focuses on results and external recognition rather than on the policy, declarations, and reports of the university itself. The QS Sustainability Rankings also provides newer empirical data, 2026 compared with 2025, and has many common features with the classical QS World University Rankings, which facilitates their joint use.

Before presenting the methods of this study, it is necessary to take into account the methodology for calculating the QS Sustainability Rankings (QS Quacquarelli Symonds, 2026), which is based on a system of parameters and includes three levels: categories ("Environmental Impact", "Social Impact", and "Governance"); lenses, or main themes, grouped by category; and the parameters included in them, namely, with the weights of the corresponding categories, lenses, and parameters indicated in brackets:

1. The category "Environmental Impact" (45%):

- "Environmental Sustainability" (15%): 'Alumni Impact for Innovation" (5%), "Member of an officially recognised sustainable group" (1%), "Climate change commitment (staff perception)" (2%), "Publicly available strategy or policy on sustainable procurement and investment" (1%), "Student Society focused on Environmental Sustainability" (1%), "Net Zero Commitment" (1%), "Emissions Efficiency" (1%), "Renewables Generated Onsite" (1%), "Progress Towards Target" (1%), "Policy on Climate Strategy" (1%);

- "Environmental Education" (17%): "Academic Reputation in Earth & Environment" (10%), "Alumni Impact for Environmental Sustainability – Public and Third Sector" (4%), "Climate Science and/or Sustainability Courses" (3%);

- "Environmental Research" (13%): "Research Impact on SDGs for Sustainable Research" (9%), "Sustainable Research National Statistics" (1%), "Research Center with an Environmental Sustainability Focus" (2%), "Policy Citations (Environmental)" (1%).

2. The category "Social Impact" (45%):

- "Equality" (12%): "Research Impact on SDGs for Equality" (4%), "Student Gender Ratio" (1%), "Faculty Gender Ratio" (1%), "Women in Leadership Ratio" (1%), "Equality, Diversity and Inclusion Policy" (1%), "Academic Equality (Staff View)" (2%), "Disability Support" (1%), "Equality National Statistics" (1%);

- "Knowledge Exchange" (10%): "Knowledge Exchange: Progress / Dissemination" (6%), "Outreach and Community Engagement" (1%), "Staff Perception" (2%), "Policy Citations (Social)" (1%);

- "Impact of Education" (7%): "Research Impact on SDGs for Education" (3%), "Academic Reputation for Impact of Education" (1%), "Alumni Impact for Education" (1%), "Academic Freedom Index" (1%), "Impact of Education National Statistics" (1%);

- "Employability & Opportunities" (11%): "Employer Reputation" (3%), "Research Impact on SDGs for Employment and Opportunities" (4%), "Employment and Opportunities National Statistics" (1%), "Partnerships with Industry" (2%), "Skills Satisfaction" (1%);

- "Health and Wellbeing" (5%): "Research Impact of SDGs for Health and Wellbeing" (3%), "Health Provision on Campus" (1%), "Health and Wellbeing National Statistics" (1%).

3. The category "Governance" (10%):

- "Good Governance" (10%): "Ethics Culture" (1%), "Open-Access Publishing" (1%), "Dedicated staff / team for Sustainable Development" (1%), "Transparent financial reporting" (1%), "Student's Union" (1%), "Student Representation in Governance" (1%), "Published governance minutes" (1%), "National Signatory to UN charter against torture" (1%), "Staff perception" (1%), "Policy Citations (Governance)" (1%).

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All parameters are combined into lenses and then into one final score according to the principle of hierarchical weighted linear aggregation, which serves as a comprehensive assessment of universities' ability to address global environmental, social, and governance problems (QS Quacquarelli Symonds, 2026).

To achieve the stated aim, the research base will cover the nine lenses of the QS Sustainability Rankings, since they are the structural analytical components, or main themes, of the ranking, namely: "Environmental Sustainability" (x_1), "Environmental Education" (x_2), "Environmental Research" (x_3), "Equality" (x_4), "Knowledge Exchange" (x_5), "Impact of Education" (x_6), "Employability & Opportunities" (x_7), "Health and Wellbeing" (x_8), "Good Governance" (x_9). These indicators, hereinafter referred to as indicators, are treated as independent variables (x_1-x_9), while the overall ranking score is treated as the dependent variable (Y).

Given the focus on studying the profiles of global leading universities, it was decided to include the first 30 positions in the QS Sustainability Rankings; however, due to identical ranking scores, 31 institutions were included in the sample (Table A1, Appendix A). The sufficiency of this number of objects is supported by the study's fairly high-quality data. Increasing the number of universities may shift the study's main focus. In this case, the sample would become less homogeneous, and the patterns characteristic specifically of leading universities would not be clear. The quality of the results would be lower, since institutions in lower positions have fundamental differences in their sustainability strategies and profiles. In addition, the aim is to find a relatively small combination of indicators that most strongly differentiates the ranked sustainability profiles of leading universities.

Given the multidimensional nature of universities' sustainable development, data mining methods are used, each justified by the analytical task. The research methodology combines the following stages:

1. Performing correlation analysis based on Pearson's coefficient to assess the strength of the linear relationship between individual indicators (x_1-x_9) and the overall ranking score (Y) across the set of universities. This will enable the identification of potentially influential variables and the formulation of analytical hypotheses for subsequent stages.

2. Conducting exploratory data analysis using principal component analysis (PCA) to determine which of the nine QS Sustainability Rankings indicators (x_1-x_9) are most strongly associated with the variation of university sustainability profiles within the sample. The search for principal components will be carried out on the basis of the singular value decomposition of the matrix.

The number of universities in the sample is only slightly above the minimum acceptable level of 27 observations (three times the number of indicators). At the same time, it remains below the more desirable level of around 45 observations. Assuming there are no random fluctuations in the data, the PCA results should be interpreted as exploratory rather than definitive.

3. Performing clustering, using the k-means method and the Euclidean distance metric, of the set of universities to identify their groups, or clusters, based on the similarity of sustainable development parameters. Covering all indicators (x_1-x_9) will enable identification of the general structure of university grouping and confirmation or refutation of differences between clusters. The stability of the distribution of universities into groups will be assessed using hierarchical and agglomerative clustering with Ward's method, which allows for a visual, structural interpretation of the data via a dendrogram. Based on a generalized analysis of indicators across university clusters, a conclusion will be drawn regarding the existence of group-specific features and the possibility of typologizing university sustainability profiles.

4. Determining the indicators among x_1-x_9 by which the university clusters obtained at the previous stage differ most strongly, based on classification analysis. This involves identifying combinations with a minimum number of parameters that ensure maximum, and, where

possible, absolute separation or delimitation of clusters, thereby indicating the most significant differences between groups of universities. Such combinations may be identified using the logical-combinatorial "decision tree" method. The assessment of the limiting separating ability of the entire training sample, each of the indicators included in it, and their combinations will be carried out according to formula (1) (Polyakov et al., 2021):

$$V\left(x_{i1},\ldots,x_{ij}\right)=\frac{1}{k}\sum_{\Delta\in\Gamma}\max_{Y}\left(\frac{m_{\Delta Y}}{m_{Y}}\right), \quad (1)$$

where k is the number of classes (clusters); m_Y is the number of objects belonging to class (cluster) Y; $\Delta = t_{i1}, t_{i2}, \ldots, t_{ij}$ $(0 \le t_{ij} \le k_{ij} - 1)$, $j = 1, \ldots, \Gamma$ means the arbitrary set of parameter values $x_{1j}, \ldots, x_{ij}(1 \le \Gamma \le n)$; $m_{\Delta Y}$ denotes the number of sampling sets of the m class, for which the relation $x_{ij} = t_{ij}(1, \ldots, \Gamma)$, is performed; t_{ij} are the values of parameters x_{ij} in the set of Δ; Γ means variety of all sets of parameter values $x_{1j}, \ldots, x_{ij}$.

In the case of complete separation of classes, estimate (1) reaches the limiting value equal to 1, or 100%. It is important to note that this estimate is calculated directly from the training sample data. The identified indicators that reflect the greatest differences between classes can be interpreted as key factors determining the specific features, or typology, of the sustainability profiles of global leading universities in the QS Sustainability Rankings.

3. RESULTS

3.1. The first stage

The correlation between each independent variable (x_1-x_9) and the dependent variable Y was analyzed using the Pandas data-processing library in the Jupyter Notebook environment. The strongest relationships with the overall score were demonstrated by the following indicators:

- "Equality" (x_4): r = 0,7376 (strong correlation);
- "Environmental Research" (x_3): r = 0,6514 (moderate to strong correlation);
- "Impact of Education" (x_6): r = 0,6213 (moderate to strong correlation);
- "Employability & Opportunities" (x_7): r = 0,5559 (moderate correlation).

This initial analysis showed that there was no very strong relationship between individual independent variables and the resulting variable. This means that the formation of the overall ranking score has a more complex and hidden structure. The indicators identified above as potentially most influential will be taken into account at the next stages. However, it is necessary to search for more complex forms of relationships. At the same time, based on the assessment of pairwise linear dependence, it can be argued that factors of social impact have a fairly strong influence on universities' positions in the QS Sustainability Rankings. The high correlation of indicators x_4, x_6, and x_7 reflects, first, the strengthening of universities' impact on society and, second, the understanding of higher education as a vehicle of social mobility. These indicators are markers of institutional quality, namely:

1. "Equality" shows the extent to which a university ensures equal opportunities for different population groups, including access to education, inclusiveness, and gender equality;
2. "Impact of Education" reflects the impact of a university's activities and educational programs on society, the orientation of education toward sustainable development, and the potential contribution of graduates to overcoming global challenges and benefiting communities in the context of the transition to sustainability;
3. "Employability & Opportunities" shows the extent to which a university provides students with the necessary competencies, helps them find employment, and creates the prerequisites for career growth after graduation.

The strong correlation of the "Environmental Research" indicator across leading global universities points to the importance of reorienting research toward new areas aimed at solving environmental problems.

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3.2. The second stage

The analysis of the nine QS Sustainability Rankings indicators using PCA was carried out in the Jupyter Notebook environment with the Scikit-learn machine learning library. According to the Kaiser criterion, the first three components (PC1–PC3) were found to have eigenvalues greater than one. The assessment of the model's informativeness shows that when the cut-off is set at three components, the cumulative variance share is 78.39%. Adding a fourth component is therefore not appropriate. The results of the calculations for the three principal components are presented in Table 1.

Of particular interest for this study are the factor loadings. They reflect the informativeness of individual indicators (x1-x9) in the structure of the principal components, that is, their influence on the formation of differences between universities. The factor loadings in the first principal component (PC1_loading) show that x8 ("Health and Wellbeing") and x5 ("Knowledge Exchange") have the strongest differentiating effect. These indicators are also strongly correlated with each other. Indicators x3 ("Environmental Research") and x6 ("Impact of Education") demonstrate moderately high significance and make a substantial contribution to the formation of overall differences between universities. The factor loadings in the second principal component (PC2_loading) show that x1 ("Environmental Sustainability") has the strongest differentiating effect. At the same time, x5 ("Knowledge Exchange") and x7 ("Employability & Opportunities") also have fairly high significance. In the third principal component (PC3_loading), only x3 ("Environmental Research") has medium informativeness. The low significance of the other indicators, in particular x2 ("Environmental Education"), is due to the fact that the global leading universities generally demonstrate a high level of performance in these areas.

Thus, the PCA-based data analysis showed that "Health and Wellbeing", "Knowledge Exchange", and "Environmental Sustainability" are most strongly associated with variation in the profiles of the global leading universities in the QS Sustainability Rankings. It should be noted that the significance of x_8 and x_5 was not revealed by the correlation analysis. This confirms the conclusion that the overall ranking score has a complex and hidden structure. The fact that x_8 and x_5 have the greatest influence on the formation of the first principal component, while x_1 has the greatest influence on the formation of the second, suggests that they form alternative hidden patterns in the data. The integral contribution shows that "Health and Wellbeing" has the strongest influence on the entire QS Sustainability Rankings system. This indicates the increasing importance of human-centeredness, with leading universities demonstrating rather different achievements.

3.3. The third stage

To divide the set of universities into groups, the optimal number of clusters was first determined using special calculation indices: the Sum of Squared Errors Index, the Davies-Bouldin Index, the Trace Index, the Calinski-Harabasz Index, the Dunn Index, and the PBM Index. A dendrogram was also constructed using the tools available on the ScienceHunter portal (URL: https://www.sciencehunter.net/Services/Clustering). The optimal number of clusters was three.

Table 1. Assessment results of the contribution of QS Sustainability Rankings indicators to the principal components

Source: Authors' calculations.

Indicators	PC1_loading	PC2_loading	PC3_loading	Integral Contribution
x_8	0.8148	0.3414	−0.1096	0.1876
x_5	0.6268	0.5569	−0.1505	0.1638
x_7	−0.4281	0.5023	−0.4123	0.1198
x_3	0.5305	0.1244	0.5575	0.1122
x_9	0.3680	−0.5696	−0.2858	0.1118
x_6	0.5589	0.2124	−0.4365	0.1103
x_1	−0.1693	0.7001	0.0420	0.1103
x_4	0.2201	−0.5480	−0.5186	0.1100
x_2	−0.4650	0.3190	−0.3909	0.0939

Table 2. Medians of QS Sustainability Rankings indicators within the obtained university clusters by ranking category

Source: Authors' calculations.

Clusters	Environmental Impact			Social Impact					Governance
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Cluster I	88.10	96.70	97.80	99.40	99.10	97.50	98.60	99.20	98.70
Cluster II	93.30	99.80	98.40	93.80	98.90	91.00	99.10	97.60	92.90
Cluster III	82.40	97.40	97.50	96.70	97.20	88.60	97.40	96.60	98.40

Next, using the tools of the above-mentioned portal, the set of universities was divided into clusters. This was verified using Ward's method. The following distribution of universities was obtained, with their positions in the QS Sustainability Rankings indicated in brackets:

- cluster I: Lund University (1), University of Toronto (2), University College London (3), The University of Edinburgh (4), University of British Columbia (5), LSE (6), UNSW Sydney (7), The University of Manchester (10), The University of Sydney (15), ANU (16), King's College London (16), The University of Melbourne (16), University of Bristol (19), KU Leuven (22), University of Helsinki (22), University of Leeds (24), University of Glasgow (27);

- cluster II: Imperial College London (7), McGill University (9), ETH Zurich (11), UCB (11), Stanford University (13), University of Oxford (14), New York University (20);

- cluster III: Pennsylvania State University (21), Durham University (24), Western University (24), The University of Auckland (28), Trinity College Dublin (29), University of Pennsylvania (30), University of Reading (30).

It should be noted separately that, in terms of the number of universities included in the study, the United Kingdom leads with 12 universities in the sample. The United States accounts for 5 universities, while Australia and Canada account for 4 universities each. Belgium, Ireland, New Zealand, Finland, Switzerland, and Sweden are represented by one university each. This illustrates the dominance of Anglo-Saxon countries and European countries.

The analysis of the QS Sustainability Rankings indicator values across the obtained university clusters indicates specific features in the orientation of sustainable development strategies. It also shows the possibility of typologizing the profiles. This is demonstrated, in particular, by the medians of indicators (x_1-x_9), presented in Table 2 by QS Sustainability Rankings categories and university clusters.

The universities included in Cluster I dominate in indicators x_4, x_5, x_6, x_8 (and also x_9). In their sustainable development strategy, they are more oriented toward increasing social impact. They also emphasize the extent to which governance is responsible, transparent, and ethical. The universities in Cluster II have the highest values for indicators x_1, x_2, and x_3. This indicates that their sustainable development strategy is oriented primarily toward strengthening environmental impact.

The universities in cluster III follow the institutions of the first two clusters in terms of the "Environmental Impact" indicators (x_1, x_2, and x_3) and part of the "Social Impact" indicators (x_5, x_6, x_7, and x_8). At the same time, they outperform cluster I in x_4 and x_9. This indicates a mixed orientation of their sustainable development strategy. These differences may serve as a basis for typologizing university profiles, which, in particular, requires identifying the differences between clusters.

3.4. The fourth stage

The basis for classification is the training sample derived from the array of empirical data (Table A1, Appendix), with universities divided into clusters (or classes) according to the results of the previous stage. Mathematical processing according to formula (1) was performed using the software implementation, implemented as a special tool available on the ScienceHunter portal (URL: https://www.sciencehunter.net/Services/Classification). The separating ability of the entire training sample was

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100%. For individual indicators, the values were as follows: x_1 – 0.59; x_2 – 0.47; x_3 – 0.38; x_4 – 0.41; x_5 – 0.50; x_6 – 0.58; x_7 – 0.40; x_8 – 0.70; x_9 – 0.35. The rather low individual informativeness requires searching for indicator combinations whose separating ability is close to that of the entire sample.

As a result of the corresponding mathematical processing, one combination was identified that fully separates all university clusters. It consists of three indicators:

- "Environmental Sustainability" (x_1) – this indicator assesses the extent to which a university implements strategies to preserve the environment. The emphasis is therefore placed on real environmental actions, including reducing emissions and energy use, managing resources and waste, participating in climate initiatives, membership in international environmental groups, and so on;
- "Impact of Education" (x_6) – the significance of this indicator was already noted during the correlation analysis and the construction of the regression model. It reflects the academic results of educational institutions aimed at sustainable development and emphasizes the importance of their social impact through strengthening critical thinking, responsibility, and values;
- "Health and Wellbeing" (x_8) – this indicator reflects the extent to which a university supports the health and wellbeing of students, teachers, and society as a whole. It covers mental and physical health, the provision of favorable and safe living conditions, access to knowledge related to health, access to medical and social services, the promotion of a healthy lifestyle, inclusiveness, support for vulnerable groups, and so on. This is also part of social impact, with the corresponding emphases.

Thus, the indicators have been identified whose combination reveals the most significant differences between clusters of institutions. In other words, they are the factors that determine the typology of the ranked sustainability profiles of leading global universities.

The inclusion of "Environmental Sustainability" (x_1) in this combination indicates that a number of leading universities, namely those in cluster II, have focused their attention specifically on environmental actions. The universities assigned to Cluster I, which comprises 17 of the 31 universities, are more concentrated on maximizing social impact parameters. This complements the QS Sustainability Rankings' analytical capacity. It enables more accurate assessment of the priorities of leading global universities in sustainable development and outlines the contours of their contributions to advancing the relevant paradigm.

4. DISCUSSION

The results of the study allow us to more accurately identify the differences between the world's leading universities in the field of sustainable development. They also deepen the analysis of the specific features of their profiles in rankings and, on this basis, of their actual strategies, compared to other approaches (Shu & Tian, 2024; de Villiers et al., 2025). The results also complement the identification of the global competitive advantages of individual universities based on the QS Sustainability Rankings. This is done not by analyzing the relationships between the QS Sustainability Rankings and leading global academic rankings, but through a comprehensive international comparison focused exclusively on sustainable development indicators (Irungu & Liu, 2024).

It should be noted that the tested approach offers much broader possibilities for classifying universities using sustainability indicators than does cluster analysis alone (Perchinunno & Cazzolle, 2020). This is because it enables the determination of the reasons for differences between clusters, that is, the factors that differentiate them. Multicriteria decision analysis (MCDA) can be used to assess universities' contributions to achieving the SDGs, thereby addressing the criticism of the ranking approach. However, it has limitations, in particular subjectivity regarding weighting coefficients (Kaloutsa et al., 2025). The proposed methodology, especially the combination of clustering and classification, offers a reliable alternative. Among other things, it makes it possible to determine weights, or the significance of indicators, objectively based on mathematical calculations by comparing a large number of universities rather than analyzing a single institution.

CONCLUSION

The study aims to analyze the structure of the QS Sustainability Rankings for global leading universities and to identify, among its components, those indicators that most strongly differentiate the ranked profiles of these institutions.

Analysis of the profiles of the top 30 universities (31 institutions due to tied ranking scores) in the QS Sustainability Rankings identified, across several stages, the indicators that strongly differentiate ranked university profiles. Correlation analysis showed that the strongest relationships with the overall QS Sustainability Rankings score were found for the following indicators: "Equality" (strong correlation); "Environmental Research" and "Impact of Education" (moderate to strong correlation); and "Employability & Opportunities" (moderate correlation). This indicates the complexity of the typology of university profiles. The principal component analysis showed that three indicators were most strongly associated with the variation of university profiles in the sample: "Health and Wellbeing", "Knowledge Exchange", and "Environmental Sustainability". The clustering of universities using the k-means method based on the nine QS Sustainability Rankings indicators revealed significant group differences in ensuring sustainability: cluster I comprises 17 universities that are more oriented toward increasing social impact; cluster II comprises 7 universities that are more oriented toward increasing environmental impact; and cluster III comprises 7 universities with mixed-orientation strategies that balance environmental and social impact. At the next stage, based on classification analysis, a combination of indicators was identified that points to the greatest differences between the obtained university clusters and, accordingly, most strongly differentiates the ranked university sustainability profiles: "Environmental Sustainability", "Impact of Education", and "Health and Wellbeing". The joint influence of these indicators explains most clearly the differences in the typology of the studied profiles of leading universities in the QS Sustainability Rankings. The proposed approach contributes to a better understanding of the actual sustainable development strategies of higher education institutions.

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APPENDIX A

Table A1. Components of QS World University Rankings: Sustainability 2026

Source: QS World University Rankings: Sustainability 2026 (QS TopUniversities, 2026).

	Rank	Overall Score	Environmental Impact			Social Impact					Governance
			Environmental Sustainability	Environmental Education	Environmental Research	Equality	Knowledge Exchange	Impact of Education	Employability & Opportunities	Health and Wellbeing	Good Governance
		Y	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Lund University	1	100	99.8	98.7	99.8	100	98.9	94.9	92.8	99.6	100
University of Toronto	2	99.8	95.1	99.9	98.8	99.8	99.3	98.4	96.4	97.4	98.7
University College London	3	99	95.8	95.5	98.1	96.8	100	94.9	99.1	99.4	99.8
The University of Edinburgh	4	98.7	90.5	98.7	97.8	96.5	98.8	97	99	99.4	99
University of British Columbia	5	98.6	88.1	99.5	98.8	99.8	99.5	97.8	96.4	97.6	98.8
LSE*	6	98.5	95.2	96.1	95.7	99.7	98.2	97.8	96.8	98.2	98.6
Imperial College London	=7	98.2	92.6	99.8	98	96.8	99	91	99.1	99.4	92.9
UNSW Sydney*	=7	98.2	89.9	99	92.3	99.7	99.3	98	99	98.2	97.7
McGill University	9	98.1	91.6	99.7	98.7	95.8	96.2	98.6	96.3	97.6	96.5
The University of Manchester	10	98	85.6	99.4	98	99.4	99	92.8	99.1	99.4	99
ETH Zurich*	=11	97.9	92.1	99.8	99.5	87.8	99.2	96.1	99.1	99	98.1
UCB*	=11	97.9	94.5	100	98.4	95.4	99.3	88.6	99.1	96.6	92.3
Stanford University	13	97.8	93.3	100	98.5	92.7	98.9	88.6	99.1	96.6	97.4
University of Oxford	14	97.7	97.7	100	98.1	93.5	98.7	99	99.1	99.4	78.3
The University of Sydney	15	97.3	86	99.5	92.2	96.8	97.9	100	98.9	98	98.4
ANU*	=16	97.2	89.7	94.8	92.1	99.4	98.3	97.7	98.3	97.6	98.5
King's College London	=16	97.2	89.7	94.4	96.9	93.6	99.1	97.5	98.9	99.2	97.8
The University of Melbourne	=16	97.2	87.6	98.3	92.2	97	98.2	99.1	99	98.2	98.2
University of Bristol	19	96.9	79	96.7	97.6	99.6	99.2	94.8	98.7	99.2	99.6
New York University	20	96.3	97.5	94.5	96.5	93.8	95.6	87.4	98.7	95.8	90.4
Pennsylvania State University	21	96.1	85.1	95.3	98.2	97.9	98.2	87.4	98.7	96.4	96.4
KU Leuven	=22	95.9	87	87.9	99.2	94.3	99.5	98.6	95.8	98.8	99.5
University of Helsinki	=22	95.9	87.9	91.4	99.6	97.1	99.1	97.3	87.2	100	99.8
Durham University	=24	95.8	82.2	94.9	96.7	96.4	97.2	92.5	98.2	97.4	99.4
University of Leeds	=24	95.8	78.2	95.4	98	96.6	99.4	96.1	98.6	99.4	98.1
Western University	=24	95.8	83.5	96.2	97.8	96.7	97.6	93.9	92.7	96.6	98.6

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Table A1 (cont.). Components of QS World University Rankings: Sustainability 2026

	Rank	Overall Score	Environmental Impact			Social Impact					Governance
			Environmental Sustainability	Environmental Education	Environmental Research	Equality	Knowledge Exchange	Impact of Education	Employability & Opportunities	Health and Wellbeing	Good Governance
		Y	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
University of Glasgow	27	95.7	77.4	96	97.4	99.5	99.7	94.7	98.1	99.2	94.3
The University of Auckland	28	95.5	76.4	99	98.1	99.6	92.6	96.5	94.5	96.2	96.5
Trinity College Dublin*	29	95.4	77.3	97.4	97.5	99.8	95.5	87.6	97.4	97.8	97.8
University of Pennsylvania	=30	95.3	93.6	99	81	95.1	96	88.4	98.9	96	98.4
University of Reading	=30	95.3	82.4	97.5	97.5	96.4	97.8	88.6	90.1	98.6	99.3

Note: * LSE – London School of Economics and Political Science; UNSW Sydney – The University of New South Wales; ETH Zurich – Swiss Federal Institute of Technology; UCB – University of California, Berkeley; ANU – Australian National University; Trinity College Dublin – The University of Dublin.