Geliş/Received: 24.04.2025 | Kabul/Accepted: 24.06.2025 | Erken Görünüm/Early View: 06.09.2025

KOCATEPEİİBFD

Research Article | Araştırma Makalesi

Performance evaluation of sustainable universities with WENSLO-based AROMAN multi-criteria decision making method: Application with GreenMetric criteria

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Abstract

Universities conduct studies aimed at creating a sustainable future and addressing environmental challenges. This commitment to sustainability drives universities to transform into sustainable institutions. This study evaluates the sustainability performance of the world's top 10 universities, as ranked by UI GreenMetric's 2023 General Report, between 2014 and 2023. The evaluation utilized criteria established by GreenMetric, including setting and infrastructure, energy and climate change, waste management, water usage, transportation, education, and research. The priority levels of these criteria were established using the WENSLO objective weighting method, which identified setting and infrastructure as the most critical factors. Following this, the AROMAN MCDM method was used to rank the universities based on their sustainability performance. Consequently, the University of Birkenfeld was recognized as the top-performing institution. Universities carry out studies to create a sustainable future addressing environmental problems. The concern for a sustainable future encourages universities to become sustainable universities. In this study, the sustainability performances of the world universities ranked in the top 10 in the 2023 general ranking report published by UI GreenMetric between 2014 and 2023 are evaluated. In the study, the criteria set by GreenMetric included setting and infrastructure, energy and climate change, waste management, water usage, transportation, education, and research. The priority level of these criteria was established by the WENSLO objective weighting method and it was determined that the most critical criterion was that of setting and infrastructure. Universities' sustainability performance was evaluated and ranked using the AROMAN MCDM method. According to this ranking, Birkenfeld University had the best performance.

Keywords: WENSLO, AROMAN, Sustainable Universities, Performance Evaluation **JEL Codes:**

WENSLO tabanlı AROMAN çok kriterli karar verme yöntemi ile sürdürülebilir üniversitelerin performans değerlendirilmesi: GreenMetric kriterleri ile uygulama

Öz

Üniversiteler, sürdürülebilir bir gelecek yaratmaya ve çevresel zorlukları ele almaya yönelik çalışmalar yürütmektedir. Sürdürülebilirlik konusundaki bu kararlılık, üniversiteleri sürdürülebilir kurumlara dönüşmeye itmektedir. Bu çalışma, UI GreenMetric'in 2023 Genel Raporu'na göre sıralanan dünyanın en iyi 10 üniversitesinin 2014-2023 yılları arasındaki sürdürülebilirlik performansını değerlendirmektedir. Değerlendirmede, GreenMetric tarafından belirlenen ortam ve altyapı, enerji ve iklim değişikliği, atık yönetimi, su kullanımı, ulaşım, eğitim ve araştırma gibi kriterler kullanılmıştır. Bu kriterlerin öncelik seviyeleri, ortam ve altyapıyı en kritik faktörler olarak belirleyen WENSLO objektif ağırlıklandırma yöntemi kullanılarak belirlenmiştir. Bunu takiben, üniversiteleri sürdürülebilirlik performanslarına göre sıralamak için AROMAN MCDM yöntemi kullanılmıştır. Sonuç olarak, Birkenfeld Üniversitesi en iyi performans gösteren kurum olarak kabul edilmiştir. Üniversiteler, çevre sorunlarını ele alarak sürdürülebilir bir gelecek yaratmak için çalışmalar yürütmektedir. Sürdürülebilir bir gelecek kaygısı, üniversiteleri sürdürülebilir üniversiteler olmaya teşvik etmektedir. Bu çalışmada, UI GreenMetric tarafından yayınlanan 2023 genel sıralama raporunda ilk 10'da yer alan dünya üniversitelerinin 2014-2023 yılları arasındaki sürdürülebilirlik performansları değerlendirilmiştir. Çalışmada GreenMetric tarafından belirlenen kriterler arasında ortam ve altyapı, enerji ve iklim değişikliği, atık yönetimi, su kullanımı, ulaşım, eğitim ve araştırma yer aldı. Bu kriterlerin öncelik düzeyi WENSLO objektif ağırlıklandırma yöntemi ile belirlenmiş ve en kritik kriterin ortam ve altyapı olduğu tespit edilmiştir. Üniversitelerin sürdürülebilirlik performansı AROMAN ÇKKV yöntemi kullanılarak değerlendirilmiş ve sıralanmıştır. Bu sıralamaya göre Birkenfeld Üniversitesi en iyi performansa sahip üniversite olmuştur.

Anahtar Kelimeler: WENSLO, AROMAN, Sürdürülebilir Üniversiteler, Performans Değerlendirme **JEL Kodları:** E31, E51, C22

Introduction

In recent years, the depletion of natural resources, unconscious consumption, natural disasters and climate change have significantly increased the awareness of resource use and environmental impacts. This awareness has made sustainability a vital issue for societies. Urban population growth, starting with the Industrial Revolution, has increased energy consumption and

How to cite this article / Bu makaleye atıf vermek için:
Bayazit Bedirhanoğlu, Ş. (2025). Performance evaluation of sustainable universities with WENSLO-based AROMAN multi-criteria decision making method: Application with GreenMetric criteria. *KOCATEPEİİBFD, 27*(2), 369-390. https://doi.org/10.33707/akuiibfd.1683204

pollution. The increasing concern worldwide and the policies and practices of governments keep the attention to sustainability on the agenda. Sustainability is tried to be realized through education, research activities and programs of universities along with individual and social attitudes. Universities consist of living spaces such as classrooms, libraries, dormitories, student centers, dining halls, parking lots, mini bazaars and restaurants. According to Kanberoğlu (2019), universities, by bringing together individuals from different regions and fostering cultural diversity within their structure, also make significant contributions to the socio-economic development of the regions in which they are located. These areas, defined as campuses, have a high density of people and buildings (Öztaş et al., 2023). Universities use resources to carry out their activities in this dense environment. These resources have a detrimental impact on the environment. Recognising the impact of university activities on the environment, university policy makers and planners have become concerned about the global implications of sustainability. This situation gained momentum with the involvement of governments, environmental protection platforms and non-governmental organizations. In 1972, during the United Nations Conference on the Human Environment in Stockholm, universities affirmed their dedication to promoting environmental sustainability within higher education, thereby enhancing their sensitivity to ecological concerns (United Nations, 1972,). In 1990, more than 300 university administrations from more than 40 countries around the world prepared a 10-point action plan, the Tallories Declaration, to incorporate sustainability and environmental literacy in all activities of university campuses for education and research (Adlong, 2013). In 1993, with the Swansea Declaration, more than 400 participating universities from 47 countries focused on how to use resources to balance technological development and environmental protection (Alshuwaikhat and Abubakar, 2008). In 2000, the US Environmental Protection Agency issued a warning that it held universities to the same standards as industry on human health and environmental issues (Savely, 2007). Efforts to address resource utilization and environmental issues are generally described by the notion of a green university (Wu, 2021).

Green university or green campus is defined as higher education institutions fulfilling their education and research functions within the framework of the aim of minimizing negative environmental impacts and creating awareness about sustainability (Dahle and Neumayer, 2001). The concept of "green", which we encounter in many different fields today, was first included in the field of education in the 90s with the expression "greening of the universities". Since 2010, with the introduction of the concepts of "green university" and "green campus" into the literature, universities have begun to play an active role in building environmentally focused sustainability with the joint action of all stakeholders (Yaşayacak, 2019). Green university refers to university campuses having an environmentally friendly structure with energy management. Universities play a crucial role in the development of an ecological civilization. The formation and sustainability of this civilization is proportional to university students gaining awareness about a sustainable future in their educational lives and starting their careers in this direction (Cortese, 2003). The definition of universities as green can be made possible by students, academics and administrative staff adopting the concept of "green" within the scope of all their activities and incorporating it into university life. With the increase in environmental problems and universities becoming more interested in these problems, the notion of sustainable university is encountered.

As a result of pressures on universities, signed commitments, voluntary efforts and the concept of green university, sustainability has started to be accepted as a part of many university systems. Sustainable university and green university are often used interchangeably. Sustainable universities are defined as higher education institutions committed to reducing the negative environmental, social, and economic impacts of their activities, while simultaneously fostering a culture of sustainability within society (Velaquez et al., 2006). Sustainable universities are an institutional component offered in response to public dissatisfaction with situations that may cause harm in the long term while aiming for gains in the short term (Marans and Edelstein, 2010). Universities are key institutions for embedding sustainable plans in society. At the same time, universities can be considered as micro cities with activities taking place on their campuses (Velazquez at al., 2006). Sustainable universities include social, economic and environmental factors. Therefore, the impact of universities on society in ensuring sustainability is undeniably important. Practices in university campus life provide a role model environment in the development of sustainability. Sustainable universities generally consist of operational activities such as energy use, water consumption, waste management, green space and transportation (Dagiliute and Liobikiene 2015). Sustainable universities are pioneering organizations in reducing or eliminating the harmful social and health impacts of environmental activities both regionally and globally (Velazquez at al., 2006).

The performances and rankings of universities on various issues are shared. United Nations Environment Network (UNEP), International Sustainable Campus Network (ISCN), World University Leaders Forum GULF, UI GreenMetric can be given as examples (Sart, 2023). Institutional rankings provide universities with the opportunity to determine their current situation and compare them with other universities. It also provides the opportunity to develop policies to improve the performance of universities. UI Greenmetric is the first initiative that ranks the sustainable activities of world universities according to various criteria (Grindsted, 2011).

UI GreenMetric was developed by Indonesia in 2010. GreenMetric is a platform that aims to present the present state and policies concerning green universities and sustainability in universities worldwide and to raise awareness about environmental awareness

(Suwartha & Sari, 2013). This platform evaluates green campus and environmental sustainability issues and ranks universities. In 2010, the ranking included 95 universities from 35 countries, while by 2023, this number had significantly increased to 1,183 universities from 84 countries. (https://greenmetric.ui.ac.id/about/welcome). UI GreenMetric raises awareness of university stakeholders by drawing their attention to issues such as setting and infrastructure, global climate change, clean energy, water conservation, waste recycling, green transportation and sustainable education and research. Since the organization is non-profit, universities can enter the rankings without paying any fees. UI GreenMetric evaluates and ranks universities globally based on their sustainability efforts. This ranking is realized by collecting numerical data from universities, converting the data into scores and ranking the universities according to their scores. The 1-year data proven by the universities participating in the platform are evaluated with a questionnaire created with 6 criteria and 39 indicators. Weights are then determined according to the calculation system and universities are ranked. Universities are evaluated under the criteria of setting and Infrastructure (SI), Energy and Climate Change (EC), Waste (WS), Water (WR), Transport (TR) and Education and Research (ED).

The evaluation of performance is regarded as a complex decision-making challenge. A decision can be defined as the judgment that emerges at the end of the decision process. Decisions involving more than one criterion and alternative are characterised as multi-criteria decisions and MCDM methods are used in their solution (Torkayesh et al., 2021). Within this study, world universities ranked in the top 10 within the scope of the evaluation made by UI GreenMetric in 2023 were evaluated according to 6 criteria. It is aimed to determine the 10-year sustainability performance of the relevant universities covering the years 2014-2023. The performance of the universities was analysed using the WENSLO and AROMAN methods, which belong to the multi-criteria decision making (MCDM) methods. The WENSLO method was employed to calculate the weights of the criteria, while the AROMAN method was utilized to rank the universities based on their sustainability performance. Although Umwelt-Campus Birkenfeld University was in the top 10 in the UI GreenMetric ranking in 2023, it was not included in the ranking in 2014. Therefore, the study was carried out with 9 universities.

Following this introduction, the study unfolds across five subsequent sections: A comprehensive literature review (Section 2) precedes the methodological framework (Section 3). The practical application is then documented (Section 4), followed by results presentation (Section 5). The work concludes with critical discussion and final recommendations (Section 6).

2. Literature Survey

In this section, a review of the literature on the subject of the study has been carried out. First of all, the literature review was conducted with the concepts of "sustainable university", "green university" and "UI GreenMetric". In addition, the literature on the analysis methods used in the study, "WENSLO" and "AROMAN" methods, was reviewed. The literature search was performed using the Web of Science, Scopus, and Google Scholar databases.

In the literature review, there are many studies on the concepts of sustainable university and green university. Finlay and Massey (2012) examined the applications of the eco-campus concept to develop a green university. Yuan et al. (2013) investigated the perspectives of university students, graduates, and parents in China on sustainable development and the idea of a green university. Katiliūtė and Staniškis (2017) examined the sustainability issues of a university in Central Europe based on a green campus with student participation. They identified concrete steps necessary for universities to become more sustainable. Bozat et al. (2016) examined the place of sustainability and sustainable university concepts related to corporate reputation in the literature. Norazah and Nrbayah (2016) examined the importance of contribution to environmental activities and green initiatives in campus sustainability. Katiliūtė et al. (2017) explored the contributions of administrative personnelin the development and implementation of green campus initiatives. Moore and Iyer-Raniga (2019) examined project and occupancy outcome evaluation measurement for a sustainable university building. Engagements with university stakeholders highlight how universities are key to fostering sustainability in urban settings. Demirkol and Birişçi (2020) examined the basic knowledge and personal thoughts of academics working at Ege University about the concept of sustainability. Fissi et al. (2021) investigated the sustainability of Florence University. The study identified the university's position in relation to sustainability. Roy (2023) measures the intention to use reusable beverage containers within the scope of green university initiatives in his study by surveying university students. The data were analyzed with structural equation modeling and provide university students with plans to encourage green behavior for environmental sustainability. Da Rosa, (2020) systematically examined the sustainability of green information technology practices in universities. Atici et al. (2021) evaluated the relationship between academic performance and green universities using the UI GreenMetric as well as the ARWU, QS, THE and NTU. The study showed that being a green university has an impact on success ranking and that environmental sustainability can provide academic advantages for universities.

Analysis shows that sustainable development concept, sustainable universities and green universities go together like the links of a chain, and that considering one separately from the other will have a negative impact on the continuation of sustainability. The notions of sustainable and green universities have been widely explored in the literature. Universities are ranked by various institutions according to various criteria in order to be green sustainable. One of them is the UI GreenMetric platform. This part of the literature review was continued by adding the words "UI GreenMetric" and "MCDM" to the keywords "sustainable" and "green" "university".

Cubilla- Montilla et al. (2022), GreenMetric 2015-2021 data statistically analysed. They concluded that education, transportation, water, waste and energy categories are interrelated. Tiyarattanachai and Hollman (2016) examined the satisfaction with sustainability practices and the perception of campus quality of living on green and non-green university campuses in Thailand with T and ANOVA tests and concluded that green university campus stakeholders are more satisfied. Görgülü et al. (2021) employed an integrated Entropy-COPRAS weighted TOPSIS approach to evaluate and rank 56 Turkish universities based on GreenMetric 2020 indicators. The ranking obtained with the study and the current situation were compared. Alawneh et al. (2021) developed an index to evaluate the contribution of sustainable campuses certified by UI GreenMetric to sustainable development goals. The global sustainability rankings of universities were evaluated within the framework of the Berlin principles by Galleli et al. (2022). Boiocchi et al. (2023) evaluated the measurement of sustainability by analyzing the GreenMetric ranking system in depth. The study recommends further work to identify appropriate indicators by which universities can more objectively assess sustainability. Efendi et al (2024) compared universities in Malaysia through qualitative analysis based on secondary data. Öztaş et al. (2023) examined 35 green universities in Europe. According to GreenMetric 2021 data, the universities were weighted by the Gini coefficient method and ranked by the MABAC method. Amrina and Imansuri (2015) evaluated Andalas University with UI GreenMetric indicators. In the research where AHP multi criteria decision making method was used, the most important criterion in sustainable university evaluation was found to be energy and climate change. Some of the studies reached through literature review are summarized in Table 1.

Table 1. UI GreenMetric Literature

Year	Author(s)	Methodology	Objectives
2018	Lemos et al.	Compilation article	Examining the sustainability of the University of Sao Paulo.
2020	Nekhoda et al.	Literature review, content analysis	Assessing the sustainable development of higher education institutions.
2021	Maçin	Literature review	Evaluating the GreenMetric performance results of Turkish universities
2022	Karasan et al.	DEMATEL, cognitive maps, VIKOR, and Fuzzy inference systems.	Determine the universities' green index
2023	Ghalehnovil and Kamelnia	Clustering Analysis	Assessing the efficiency and performance of 42 Iranian universities
2023	Yakymchuk et al.	Regression analysis.	Examining the regression between energy, climate change and aggregate assessment indices
2023	Akyol Özcan	TOPSIS, CRITIC, ENTROPY, equal weighting, Standard Deviation	Sustainability ranking of Turkish universities
2023	Matulová	DEA	Analysing the connection between UI GreenMetric rankings and sustainable development goals of European universities
2024	Aregarot et al.	AHP, WAM	Assess how a university's sustainability practices are influenced by its UI GreenMetric score.

In reviewing the relevant literature shows that there are studies that consider the sustainability of universities and examine UI GreenMetric performance rankings using multi-criteria decision making methods. A review of the studies shows that there is a concentration on countries, regions or universities, and that sustainable university evaluations are evaluated over a short period of time. In this study, the last 10-year sustainability performances of the world universities ranked in the top 10 within the scope of the evaluation made by UI GreenMetric in 2023 were ranked with WENSLO objective weighting and AROMAN multi-criteria decision-making method. The research is anticipated to enrich the literature by examining a large number of universities, analyzing their performance over a decade, and pioneering the application of the WENSLO and AROMAN methods, which are innovative and previously unexplored in existing studies.

3. Methods

In this study, the criteria were weighted using the Weights by Envelope and Slope (WENSLO) method. The sustainability-based ranking of universities was performed using the AROMAN with two-Step Normalization, a robust multi-criteria decision-making (MCDM) technique. This section outlines the methodological framework, including its key computational stages and implementation procedures.

3.1. WENSLO Method

The WENSLO method was introduced to the literature by Pamucar et al. (2023). WENSLO method is employed to identify the objective weighting of criteria. The method allows determining the trend or change in each criterion. The method is simple and easy in terms of calculation. The WENSLO method, expressed as weighting with envelope and slope, differs from traditional methods in calculating objective weights. The method is better suited for decision-making problems that consider the refinement or weighting of the criteria. It is also advantageous because the criterion trend has no effect in the calculation process and the criterion weights are independent of individual judgment. However, the method requires processing and analysis of a large amount of raw data. This may affect the final results.

The WENSLO method consists of the following key stages (Pamucar et al., 2023):

Stage 1: Creating the decision-making matrix: The decision-making matrix is presented in Equation (1).

$$\Re(\mathrm{A,C}) = [\zeta_{\mathrm{ij}}]_{\mathrm{mxn}} = \begin{bmatrix} \mathrm{A/C} & \mathrm{C_1} & \mathrm{C_2} & \dots & \mathrm{C_J} \\ \mathrm{target} & \mathrm{maxmin} & \mathrm{maxmin} & \dots & \mathrm{maxmin} \\ \mathrm{A_1} & \zeta_{11} & \zeta_{12} & \dots & \zeta_{1\mathrm{j}} \\ \mathrm{A_2} & \zeta_{21} & \zeta_{22} & \dots & \zeta_{2\mathrm{j}} \\ \dots & \dots & \dots & \dots & \dots \\ \mathrm{A_i} & \zeta_{\mathrm{i}1} & \zeta_{\mathrm{i}2} & \dots & \zeta_{\mathrm{mn}} \end{bmatrix} \tag{1}$$

In the matrix, A_1, A_2, …, A_m is the alternative vector space representing the group of alternatives and m is the number of alternatives. C_1, C_2, …, C_n represents the criteria vector space regarding the criteria group, and n denotes the number of criteria. Maxmin, the objective of each criterion, aims to maximise the value of a benefit criterion and minimise the value of a cost criterion (Pamucar et al., 2023).

Stage 2: Input data normalization: Criteria are categorised according to certain characteristics. Therefore, a decision-making matrix becomes multidimensional and calculation becomes very difficult. To overcome this difficulty, a normalization process is performed. The normalization action is given by Equation (2) (Pamucar et al., 2023).

$$z_{ij} = \frac{\zeta_{ij}}{\sum_{i=1}^{m} \zeta_{ij}} \qquad \forall \mathrm{j} \in [1,2,\dots,\mathrm{n}] \tag{2}$$

The normalized decision matrix is represented by the Equation (3). Here z_{ij} denotes component of the normalized decision matrix and $0 \leq z_{ij} \leq 1$.

$$Z(A,C) = [\mathrm{z}_{ij}]_{mxn} = \begin{bmatrix} A/C & C_1 & C_2 & \dots & C_J \\ target & maxmin & maxmin & \dots & maxmin \\ A_1 & \mathrm{z}_{11} & \mathrm{z}_{12} & \dots & \mathrm{z}_{1j} \\ A_2 & \mathrm{z}_{21} & \mathrm{z}_{22} & \dots & \mathrm{z}_{2j} \\ \dots & \dots & \dots & \dots & \dots \\ A_i & \mathrm{z}_{i1} & \mathrm{z}_{i2} & \dots & \mathrm{z}_{mn} \end{bmatrix} \tag{3}$$

Stage 3: Calculation of the class range of the criteria: The final ranking of alternatives is closely tied to the criteria's influence (Pamucar et al., 2023). In decision theory, it is crucial to objectively define this effect, known as criterion weights. Equation (4) illustrates the normalized decision matrix.

$$\begin{bmatrix} A \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ \cdot \\ A_\mathrm{i} \end{bmatrix} = \left(\begin{bmatrix} C \\ z_{11} \\ z_{21} \\ \cdot \\ \cdot \\ \cdot \\ z_{i1} \end{bmatrix}, \begin{bmatrix} C \\ z_{12} \\ z_{22} \\ \cdot \\ \cdot \\ \cdot \\ z_{i2} \end{bmatrix}, \dots, \begin{bmatrix} C \\ z_{1j} \\ z_{2j} \\ \cdot \\ \cdot \\ \cdot \\ z_{ij} \end{bmatrix} \right) \tag{4}$$

The size of the class interval for the jth criterion (Δ_{zj})is calculated using Sturges' rule as shown in Equation (5):

$$\Delta_{zj} = \frac{\underbrace{max}_{i=1,2,\dots,m} \; z_{ij} - \underbrace{min}_{i=1,2,\dots,m} \; z_{ij}}{1 + 3.322 \cdot \log(m)} \qquad \forall \mathrm{j} \in [1,2,\dots,\mathrm{n}] \tag{5}$$

According to Equation (5), the class intervals Δ_{z1} and Δ_{z2} for criteria C_1 - C_2 are;

$$\Delta_{z1} = \frac{\underbrace{max}_{i=1,2,\dots,m} \quad z_{i1} - \underbrace{min}_{i=1,2,\dots,m} \quad z_{i1}}{1 + 3.322 \ \cdot \log(m)}$$
$$\Delta_{z2} = \frac{\underbrace{max}_{i=1,2,\dots,m} \quad z_{i2} - \underbrace{min}_{i=1,2,\dots,m} \quad z_{i2}}{1 + 3.322 \ \cdot \log(m)} \tag{6}$$

Stage 4: Calculate the criterion slope: Calculate the criterion slope using Equation (7) (Pamucar et al., 2023).

$$\tan \varphi_j = \frac{\sum_{i=1}^{m} z_{ij}}{(m-1) \cdot \ \Delta_{zj}} \qquad \forall j \ \in \ [1,2, \dots, n] \tag{7}$$

Stage 5: Calculate of the criterion envelope: The Euclidean distance between the first normalised value and the last normalised value of the jth criterion is determined by Equation (8). This distance is obtained by summing the Euclidean distances between two consecutive normalised values (Pamucar et al., 2023).

$$E_j = \sum_{i=1}^{m-1} \sqrt{(z_i + 1, j - z_{i,j})^2 + \Delta_{z^2 j}} \qquad \forall j \ \in \ [1,2,3, \dots, n] \tag{8}$$

The total Euclidean distance, forming a zigzag-shaped criterion envelope, represents the values.

Stage 6: Calculate the envelope-slope ratio: The envelope slope ratio is calculated by the ratio of the Euclidean distance to the criterion as given in Equation (9) (Pamucar et al., 2023).

$$q_j = \frac{E_j}{\tan \varphi_j} \quad \forall j \in \ [1,2,3, \dots, n] \tag{9}$$

Stage 7: Determining the weights of the criteria: Criteria weight are calculated as in Equation (10);

$$w_j = \frac{q_j}{\sum_{i=1}^{n} q_j} \quad \forall j \in \ [1,2,3, \dots, n] \tag{10}$$

The method involves collecting normalized standard values given a set of alternatives. The normalized data may be interpreted as time series data. Generally, these series do not have a strict order. Even if the standard data are quite complex, they still follow some basic principles. The main goal of the accumulation is to determine the real laws of the standard based on the available data. It becomes easier to ascertain the properties of this criterion when the randomness of the data is smoothed out. By applying the accumulation process to the original normalized series, the resulting series clearly exhibits a growth trend. $Z_j = \{z_1(A_1), \ z_j(A_2), \dots, z_j(A_i)\}$ for $i = 1,2,3, \dots, m$ and $\forall j \in \ [1,2,3, \dots, n]$ denote the normalized value sequence for criterion j across all alternatives (Pamucar et al., 2023).

It is evident that the sequence Z_j can be interpreted as time series by substituting time points with alternative values, expressed as Z(t)= {z(1), z(2), …, z(T). The span between two successive alternatives aligns with the time gap between corresponding points. Therefore, this time gap can be viewed as a criterion-based class interval. In other words, Δt=Δzj ∀j∈ [1,n]. When the accumulation process is apllied to the sequence Z_j, the resulting sequence corresponds to Equation (11) (Pamucar et al., 2023):

$$Z_j(\mathrm{i}, \Delta z_j) = \{0, z_{1j}, z_{2j}, \dots, z_{ij}\} \ \ i = 1,2, \dots, m-1 \ \ \forall j \in \ [1, n] \tag{11}$$

Here $z_{kj} = \sum_{i=1}^{k} z_{ij}$ k=2,3,…,m, foundational principles of accumulation derive from Grey System Theory (Aczel and Alsina, 1982). Through linear normalization, the cumulative result converges to unity. Since criterion values may be interpreted as temporal data sequences, the accumulation procedure serves to mitigate criterion fluctuations while providing a framework for slope computation. This process yields two distinct outcomes:

i. A piecewise linear representation (or multiple segments) depicting actual criterion accumulation. ii. A hypotenuse corresponding to synthetic accumulation.

The synthetic accumulation for any criterion is constructed via a linear function intersecting coordinates (0;0) and $((m-1) \cdot \Delta z_j; 1)$. Consequently, the linear functions governing synthetic knowledge accumulation are formally expressed as Equation (12), (Pamucar et al., 2023):

$$\hat{z}_j \left(\mathrm{i}, \Delta z_j\right) = \tan \varphi_j \left(\mathrm{i} \cdot \Delta z_j\right) \ \ i = 0,1,2,3 \dots, m-1 \ \ \forall j \in \ [1, n] \tag{12}$$

An artificial cumulative set of criteria is created by the previous function.

$$\hat{Z}_j\left(\mathrm{i}, \Delta z_j\right) = \left\{0, \hat{z}_{1j}, \hat{z}_{2j}, \dots, \hat{z}_{ij}\right\}\; i = 1,2,3, \dots, m-1 \;\; \forall \mathrm{j} \in [1, \mathrm{n}] \quad (13)$$

Validation of the synthetic accumulation trajectory requires rigorous examination. The discrepancy between observed and synthetic accumulated values, termed synthetic accumulation error (EAA), is quantified as:

$$\varepsilon_i\left(\Delta z_j\right) = z_{ij} - \hat{z}_{ij}, \qquad i = 1,2,3, \dots, m-1 \;\; \forall \mathrm{j} \in [1, \mathrm{n}] \quad (14)$$

The EAA serves as a metric to compare natural and constructed accumulation patterns. For each decision alternative (time point), the calculation of the EAA for the jth criterion produces the error sequence.

$$\varepsilon_j\left(\mathrm{i}, \Delta z_j\right) = \left\{\varepsilon_{1j}, \varepsilon_{2j}, \dots, \varepsilon_{ij}\right\}, \qquad i = 1,2,3, \dots, m-1 \;\; \forall \mathrm{j} \in [1, \mathrm{n}] \quad (15)$$

Two principal methodologies assess the artificial accumulation's validity:

i- Quadratic mean deviation (MSE)

ii- Association metric (Pearson's r)

Upon satisfying validation thresholds, the criterion's inclination can be derived from the synthetic accumulation model's hypothetical slope. The MSE quantifies the proximity between the derived slope and actual cumulative measurements - diminishing MSE values indicate enhanced congruence. Bivariate examination through correlation analysis reveals both magnitude and directionality of the relationship between authentic and synthetic accumulation. A correlation coefficient r within [0.8, 1] denotes exceptional association strength, permitting hypotenuse-based slope determination (Pamucar et al., 2023).

3.2. AROMAN Method

Decision-making problems are problems where more than one criteria are taken into account to identify the optimal alternative from a certain set, unlike single-criteria approaches. Methods such as AHP, CoCoSo, DEMATEL, ARAS, ELECTRE, SWARA, and PROMETHEE are some of the MCDM methods used to solve various problems. These methods primarily rely on similar principles of decision-making. Decision making involves a matrix comparing various alternatives against multiple conflicting criteria (Bošković et al., 2023).Through any Multi Criteria Decision Making (MCDM) method, the decision maker can rank these alternatives to choose the best option.

The AROMAN method, introduced by Bošković et al., integrates normalized data through a two-step normalization process and generates an average matrix from this normalized data (Dabic-Miletic et al., 2024).

The method is detailed in the following stages (Bošković et al., 2023):

Stage 1: Define the initial decision-making matrix: Before commencing the analytical procedure, the assessment structure is formulated using the initial dataset. Relevant information is collected beforehand, accounting for all potential options and evaluation parameters. The dataset comprises elements ζ_{12}, …,ζ_{2j},…, ζ_{mn}, with the complete evaluation structure ζ_{mxn}mathematically represented in Equation (1) (Bošković et al., 2023).

Stage 2: The input data normalisation: Following framework construction, the second phase involves data standardization. This process transforms raw values into a dimensionless [0,1] interval through linear scaling. Two distinct standardization approaches are mathematically defined in Equations (16) and (17), (Bošković et al., 2024).

$$t_{ij} = \left\{\frac{\zeta_{ij} - \min\zeta_{ij}}{\max\zeta_{ij} - \min\zeta_{ij}}, i = 1,2, \dots, m, j = 1,2, \dots, n \; (Type\ 1) \right. \quad (16)$$

$$t_{ij}{}^{*} = \frac{\zeta_{ij}}{\sqrt{\sum_{i=1}^{m} \zeta_{ij}^2}} \qquad i = 1,2, \dots, m, j = 1,2, \dots, n \; (Type\ 2) \quad (17)$$

Normalization methods in Equation (17) are utilized for criteria types, whether benefit-oriented or cost-oriented. The total average normalization is achieved through Equation (18).

$$t_{ij}{}^{norm} = \frac{\beta\zeta_{ij} + (1-\beta)t_{ij}{}^{*}}{2} \; i = 1,2, \dots, m, j = 1,2, \dots, n \quad (18)$$

Stage 3: Multiply the Aggregated Averaged Normalized decision-making matrix by the criteria weights to derive the weighted decision-making (DM) matrix, as shown in Equation (19) (Pishahang et al.,2023).

$$\hat{t}_{ij} = W_{ij} \cdot t_{ij}{}^{norm} \qquad i = 1,2, \dots, m, j = 1,2, \dots, n \tag{19}$$

Stage 4: Total scores of the alternatives for the criterion types are obtained. If the criterion type is minimum, L_i, if it is maximum, B_i are determined by equations (20) and (21), respectively.

$$L_i = \sum_{i=1}^{n} \widehat{t_{ij}}^{(min)} \qquad i = 1,2, \dots, m, j = 1,2, \dots, n \tag{20}$$

$$A_i = \sum_{i=1}^{n} \widehat{t_{ij}}^{(max)} \qquad i = 1,2, \dots, m, j = 1,2, \dots, n \tag{21}$$

Stage 5: Calculate the final ranking of the alternatives: Equality (22) is applied to calculate conclusive ranking of the alternatives (R_i) as follows (Bošković et al., 2023)

$$R_i = e^{\left((A_i{}^{(1-\lambda)})-\left(L_i{}^{\lambda}\right)\right)} \qquad i = 1,2, \dots, m \tag{22}$$

The ranking index (R_i) denotes the ordered alternatives, while λ signifies the weighting parameter for criterion classification (Özekenci, 2024). When a study incorporates both criterion categories, λ defaults to 0.5. As an illustration, a decision scenario containing two minimizing criteria and one maximizing criterion would yield λ=2/3. This weighting scheme enables systematic alternative prioritization. The AROMAN methodology's procedural sequence is visualized in Figure 1 (Bošković et al., 2023).

Figure 1. AROMAN Method Flowchart

Source: (Bošković et al., 2023)

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4. Performance Analysis of Sustainable Universities with WENSLO Based AROMAN Method

The study examined, the universities ranked in the top ten in 2023 according to the sustainability performance of the universities published by UI GreenMetric were analyzed. The average of the 10-year data of the relevant universities covering the periods 2014-2023 was taken. The universities ranked in the top 10 in the 2023 UI GreenMetric evaluation, their codes and 2023 overall performances are given in Table 2.

Table 2. Universities Included in the Study

Ranking	Name of university	University Code	2023 UI GreenMetric Overall Performance Total Score
1	Wageningen University & Research	WUR	9500
2	Nottingham Trent University	NTU	9450
3	Umwelt-campus Birkenfeld (trier University of Applied Sciences)	UCB	9450
4	University of Groningen	UG	9450
5	University of California, Davis	UCD	9425
6	University College Cork	UCC	9425
7	University of Nottingham	UN	9425
8	Universidade De Sao Paulo Usp	USP	9425
9	University of Connecticut	UC	9400
10	Universitat Bremen	UB	9375

Umwelt-campus Birkenfeld University could not be included in the study because it was not included in the 2014 UI GreenMetric performance assessment. The criteria included in the assessment within the scope of the study were obtained from UI GreenMetric. These criteria can be listed as; setting and infrastructure (CR1), energy and climate change (CR2), waste (CR3), water (CR4), transportation (CR5), education and research (CR6). Criteria C1, C5 and C6 are benefit-oriented, while criteria C2, C3 and C4 are cost-oriented. A two-stage method was determined to rank sustainable universities in the study. In the first stage, the criteria weights were determined with the WENSLO method to objectively determine the importance levels of the criteria. In the second stage, the performances of the 9 selected universities were analyzed with the AROMAN method. The first decision matrix obtained by averaging the 10-year data of the relevant universities as part of the criteria included in the study is given in Table 3.

Table 3. Decision-making Matrix

	max	min	min	min	max	max
	CR1	**CR2**	**CR3**	**CR4**	**CR5**	**CR6**
WUR	1102	1623	1792	940	1356	1533
NTU	1107	1667	1747	847	1365	1470
UG	906	1532	1732	960	1486	1349
UCD	1190	1618	1755	962	1477	1373
UCC	987	1644	1720	881	1481	1372
UN	1155	1649	1777	982	1444	1410
USP	1118	1231	1510	757	1240	1245
UC	1140	1503	1692	942	1424	1426
UB	912	1413	1580	905	1455	1290

4.1. Determination of Criteria Weight Coefficients with WENSLO Method

The initial stage in the method involves establishing the decision matrix provided in Table 2. The normalized matrix in Table 4 was obtained by normalizing the data in the table with Equation (2). (Due to space limitations in the study, only six digits after the decimal point are shown in the tables.)

Table 4. Decision Matrix Normalized

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0,114589	0,116931	0,117086	0,114971	0,106537	0,122955
NTU	0,115109	0,120101	0,114146	0,103596	0,107244	0,117902
UG	0,094208	0,110375	0,113166	0,117417	0,116750	0,108197
UCD	0,123739	0,116571	0,114668	0,117661	0,116043	0,110122
UCC	0,102631	0,118444	0,112382	0,107754	0,116358	0,110042
UN	0,120099	0,118804	0,116106	0,120108	0,113451	0,113089
USP	0,116252	0,088689	0,098661	0,092588	0,097423	0,099856
UC	0,118540	0,108285	0,110552	0,115215	0,111879	0,114373
UB	0,094832	0,101801	0,103234	0,110689	0,114315	0,103465

The third stage is to calculate the range of the standard category using Equation (5). The calculation results of the standard category range are as follows, as shown in Table 5.

$$\Delta z_{c1} = \frac{0{,}123739211812416 - 0{,}0942081730269315}{1 + 3.322 \cdot \log(9)} = 0{,}0070817947225732$$

$$\Delta z_{c1} = \frac{0{,}120100864553314 - 0{,}0886887608069164}{1 + 3.322 \cdot \log(9)} = 0{,}00753289012797979$$

…

…

Table 5. Width of the jth Standard Class Interval

Criterion	CR1	CR2	CR3	CR4	CR5	CR6
Δz_j	0,007082	0,007533	0,004419	0,006599	0,004635	0,005539

The assessment of criterion j proceeds along its designated dimension, initialized at origin (0,0), with this dimension mapping the alternative space. Consequently, the spatial coordinate of alternative j along the Δz_j dimension requires formalization. The axis calibration is: $posA_{i+1}(j) = i \cdot \Delta z_j, i = 0,1,2,\ldots,m-1$ $\forall j \in [1, n]$. Thus, alternative j's coordinate aligns with Equation (12)'s secondary component. Hence, the ith alternative aligns with the second component of Equation (12).The main function of the grading is to create a precondition to capture the criterion behavior more easily. The calculation of the alternative position for the CR1 criterion is presented in the figure below and given in Table 6.

$$posA_1 = 0 \cdot 0{,}0070817947225732 = 0$$

$$posA_2 = 1 \cdot 0{,}0070817947225732 = 0{,}007082$$

$$posA_2 = 2 \cdot 0{,}0070817947225732 = 0{,}014164$$

…

…

Table 6. Graduation of Criteria or Positioning of Alternatives

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0	0	0	0	0	0
NTU	0,007082	0,007533	0,004419	0,006599	0,004635	0,005539
UG	0,014164	0,015066	0,008837	0,013199	0,009269	0,011079
UCD	0,021245	0,022599	0,013256	0,019798	0,013905	0,016618
UCC	0,028327	0,030132	0,017674	0,026398	0,018539	0,022157
UN	0,035409	0,037664	0,022093	0,032997	0,023174	0,027697
USP	0,042491	0,045197	0,026511	0,039597	0,027809	0,033236
UC	0,049573	0,052730	0,030929	0,046196	0,032444	0,038776
UB	0,056654	0,060263	0,035348	0,052795	0,037079	0,044315

In the fourth stage of the WENSLO method, the criterion slope is calculated. The calculation made with Equation (7) is presented as follows and given in Table 7.

$$\tan \varphi_{c1} = \frac{0{,}114589 + 0{,}115109 + \cdots + 0{,}11854}{(9-1) \cdot 0{,}007082} = 17{,}65089$$

$$\tan \varphi_{c2} = \frac{0{,}116931 + 0{,}120101 + \cdots + 0{,}101801}{(9-1) \cdot 0{,}007082} = 16{,}5939$$

…

…

Table 7. Criteria Slope Values

Slope	CR1	CR2	CR3	CR4	CR5	CR6
Values	17,650892	16,593896	28,289783	18,941037	26,969348	22,565746

The next stage is to determine the criterion envelope using Equation (8). The overall Euclidean distance between the normalized starting and ending values of the jth term, termed the criterion envelope, is presented in Table 8.

Table 8. Criteria Envelope Values

Criteria envelope values	CR1	CR2	CR3	CR4	CR5	CR6
	0,140896	0,107509	0,064485	0,120851	0,067171	0,078517

In the sixth stage, the envelope slope ratio of the criteria is calculated using the help of equation (9). The calculation is presented below and is given in Table 8.

$$q_{c1} = \frac{E_{c1}}{\tan\varphi_{c1}} = \frac{0{,}140896}{17{,}65089} = 0{,}007982$$

$$q_{c2} = \frac{E_{c2}}{\tan\varphi_{c2}} = \frac{0{,}107509}{16{,}5939} = 0{,}006479$$

...

...

Table 9. Envelope Slope Ratios

Envelope-slope ratios	CR1	CR2	CR3	CR4	CR5	CR6
	0,007982	0,006479	0,002279	0,006380	0,002490	0,003479

The final weight coefficient values of the criteria are obtained by additive normalization of the envelope slope ratios. The weights and rankings obtained with Equation (10) are presented as follows and given in Table 10.

$$w_1 = \frac{0{,}07982}{0{,}029091} = 0{,}274391$$

$$w_2 = \frac{0{,}006479}{0{,}029091} = 0{,}222708$$

...

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Table 10. Final Weighting of the Criteria

Final criteria weight values	CR1	CR2	CR3	CR4	CR5	CR6
	0,274391	0,222708	0,078355	0,219324	0,085615	0,119606
Rank	1	2	6	3	5	4

The verification process involves comparing the artificial and real data accumulations of normalized criteria (Pamucar et al., 2023). The real accumulated values obtained using Equation (11) are given in Table 11.

Table 11. Real Accumulates Values

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0	0	0	0	0	0
NTU	0,229697	0,237032	0,231232	0,218567	0,213781	0,240857
UG	0,323906	0,347406	0,344397	0,335983	0,330531	0,349054
UCD	0,447645	0,463977	0,459066	0,453645	0,446574	0,459175
UCC	0,550276	0,582421	0,571447	0,561399	0,562932	0,569217
UN	0,670375	0,701225	0,687553	0,681507	0,676383	0,682307
USP	0,786628	0,789914	0,786214	0,774095	0,773806	0,782162
UC	0,905168	0,898199	0,896766	0,889310	0,885685	0,896535
UB	1	1	1	1	1	1

The artificial values of the accumulation are obtained by Equation (12) and are given in Table 12.

$$\hat{z}_1\ (\mathrm{i} = 0, \Delta z_{c1} = 0{,}007082) = 17{,}65089 \cdot (0 \cdot 0{,}007082) = 0$$

$$\hat{z}_2\ (\mathrm{i} = 1, \Delta z_{c1} = 0{,}007082) = 17{,}65089 \cdot (1 \cdot 0{,}007082) = 0{,}125$$

...

...

Table 12. Artificial Accumulated Values

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0,125	0,125	0,125	0,125	0,125	0,125
NTU	0,25	0,25	0,25	0,25	0,25	0,25
UG	0,375	0,375	0,375	0,375	0,375	0,375
UCD	0,5	0,5	0,5	0,5	0,5	0,5
UCC	0,625	0,625	0,625	0,625	0,625	0,625
UN	0,75	0,75	0,75	0,75	0,75	0,75
USP	0,875	0,875	0,875	0,875	0,875	0,875
UC	1	1	1	1	1	1
UB	1	1	1	1	1	1

The squared accumulation error for i = 1 is presented as follows and is shown in Table 13.

$$\varepsilon_1\ (\Delta z_1) = z_1 - \hat{z}_1 = 0 - 0 = 0$$

$$\varepsilon_1\ (\Delta z_1) = z_1 - \hat{z}_1 = 0{,}229697\text{-}0{,}125\text{=}0{,}104697$$

…

…

Table 13. Errors of the Accumulation

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0	0	0	0	0	0
NTU	0,104697	0,112032	0,106232	0,093567	0,088781	0,115857
UG	0,073906	0,097406	0,094397	0,085983	0,080531	0,099054
UCD	0,072645	0,088977	0,084066	0,078645	0,071574	0,084175
UCC	0,050276	0,082421	0,071447	0,061399	0,062932	0,069217
UN	0,045375	0,076225	0,062553	0,056507	0,051383	0,057307
USP	0,036628	0,039914	0,036214	0,024095	0,023806	0,032162
UC	0,030168	0,023199	0,021766	0,014310	0,010685	0,021535
UB	0	0	0	0	0	0

The squared errors are given in Table 14. The average MSE value of all criteria is 0.003853.

Table 14. Squared Error and Correlation

	CR1	CR2	CR3	CR4	CR5	CR6
Mean squared error	0,003171	0,004966	0,00423	0,003342	0,002975	0,004433
Coefficient of correlation	0,995509	0,992925	0,99396	0,994981	0,995523	0,993386

4.2. Evaluation of Alternatives with AROMAN Method

In the first stage of the AROMAN method, the decision matrix (Table 2) is determined. The DM matrix is normalized with Equations (16-17). Normalized matrices for both types are given in Table 15 and Table 16.

Table 15. Normalization Decision Matrix Type 1

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0,690141	0,899083	1	0,813333	0,471545	1
NTU	0,707746	1	0,840426	0,4	0,50813	0,78125
UG	0	0,690367	0,787234	0,902222	1	0,361111
UCD	1	0,887615	0,868794	0,911111	0,963415	0,444444
UCC	0,285211	0,947248	0,744681	0,551111	0,979675	0,440972
UN	0,876761	0,958716	0,946809	1	0,829268	0,572917
USP	0,746479	0	0	0	0	0
UC	0,823944	0,623853	0,64539	0,822222	0,747967	0,628472
UB	0,021127	0,417431	0,248227	0,657778	0,873984	0,15625

Table 16. Normalization Decision Matrix Type 2

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0,342271	0,34945	0,350776	0,343975	0,319146	0,368208
NTU	0,343824	0,358924	0,341967	0,309943	0,321265	0,353076
UG	0,281396	0,329857	0,339031	0,351293	0,349743	0,324013
UCD	0,369604	0,348373	0,343533	0,352025	0,347625	0,329778
UCC	0,306554	0,353971	0,336682	0,322385	0,348566	0,329537
UN	0,358733	0,355048	0,347839	0,359344	0,339858	0,338664
USP	0,347241	0,265048	0,295575	0,277009	0,291845	0,299034
UC	0,354074	0,323613	0,331201	0,344706	0,335151	0,342507
UB	0,283259	0,304235	0,309278	0,331167	0,342447	0,309842

After normalization of the decision matrix, the weighted DM matrix is obtained. The matrix obtained with Equation (18) is presented in Table 17. ($\beta = 0{,}5$)

$$t_1{}^{norm} = \frac{0{,}5\cdot 0{,}690140845+(1-0{,}5)0{,}342271497}{2} = 0{,}258103086$$

$$t_2{}^{norm} = \frac{0{,}5\cdot 0{,}707746479+(1-0{,}5)0{,}343824453}{2} = 0{,}262892733$$

Table 17. Aggregated Averaged Normalized

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0,258103	0,312133	0,337694	0,289327	0,197673	0,342052
NTU	0,262893	0,339731	0,295598	0,177486	0,207349	0,283581
UG	0,070349	0,255056	0,281566	0,313379	0,337436	0,171281
UCD	0,342401	0,308997	0,303082	0,315784	0,327759	0,193555
UCC	0,147941	0,325305	0,270341	0,218374	0,332060	0,192627
UN	0,308873	0,328441	0,323662	0,339836	0,292282	0,227895
USP	0,273429	0,066262	0,073894	0,069252	0,072961	0,074758
UC	0,294504	0,236866	0,244148	0,291732	0,270779	0,242745
UB	0,076096	0,180416	0,139376	0,247236	0,304108	0,116523

The weighted DM matrix obtained by multiplying the total average normalized DM matrix with the criterion weights with Equation (19) is presented below and given in Table 18.

$$\hat{t}_1 = 0{,}258103\cdot 0{,}274391 = 0{,}070821$$

$$\hat{t}_2 = 0{,}262893\cdot 0{,}274391 = 0{,}072136$$

…

…

Table 18. Aggregated Averaged Weighted Normalized Decision-Making Matrix

	CR1	CR2	CR3	CR4	CR5	CR6
WUR	0,070821	0,069515	0,02646	0,063456	0,016924	0,040912
NTU	0,072136	0,075661	0,023162	0,038927	0,017752	0,033918
UG	0,019303	0,056803	0,022062	0,068731	0,02889	0,020486
UCD	0,093952	0,068816	0,023748	0,069259	0,028061	0,02315
UCC	0,040594	0,072448	0,021183	0,047895	0,028429	0,023039
UN	0,084752	0,073146	0,025361	0,074534	0,025024	0,027258
USP	0,075027	0,014757	0,00579	0,015189	0,006247	0,008942
UC	0,080809	0,052752	0,01913	0,063984	0,023183	0,029034
UB	0,020880	0,040180	0,010921	0,054225	0,026036	0,013937

The total scores of the alternatives for the criteria were obtained with the equation (20-21) and are given in Table 19.

$$L_1 = \sum_{i=1}^{n} \widehat{t_{ij}}^{(min)} = 0{,}0695145180 + 0{,}264600020 + 0{,}63456338 = 0{,}159430858$$

…

$$A_1 = 0{,}070821+0{,}016924+0{,}040912=0{,}128656682$$

….

Table 19. Total of All Minimization-Type Criteria (Li)

	Sum of all minimum criteria Li	Sum of all maximum criteria Ai
WUR	0,159430858	0,128656682
NTU	0,137749232	0,123805888
UG	0,147596577	0,068679112
UCD	0,16182306	0,145163615
UCC	0,141525134	0,092062709
UN	0,173041078	0,137033717
USP	0,035735718	0,090215023
UC	0,135866084	0,133026212
UB	0,105325808	0,060853393

In the last stage, the final ranking of the alternatives was obtained by equation (22) and is presented in Table 20.

$$R_i = e^{0,128656682^{0,5} - 0,159430858^{(1-0,5)}} = 0,960216705$$

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Table 20. Final Ranking

	Final Ranking	Rank
WUR	0,960216705	5
NTU	0,980901504	3
UG	0,885056904	9
UCD	0,978957808	4
UCC	0,929812482	7
UN	0,955236179	6
USP	1,117738762	1
UC	0,996135307	2
UB	0,925106418	8

5. Findings

In this part of the study, the results obtained using WENSLO and AROMAN are presented. When the weights of the criteria obtained from the data obtained from WENSLO and the UI GreenMetric platform are examined, it is seen that the most important criterion is the setting and infrastructure criterion (CR1=0.274391). The energy and climate change criterion (CR2=0.22708) is in second place. Other criteria are listed with the weights of water (CR4=0.219324), education and research (CR6=0.119606), transportation (CR5=0.085615), waste (CR3=0.078355). The ranking of sustainable universities was calculated by integrating the weight values obtained with the WENSLO method into the AROMAN method. The results of the study show that, the university with the optimal performance between 2014-2023 was the University of Nottingham, while the university with the lowest performance was the Umwelt-campus Birkenfeld (trier University of Applied Sciences). The second best performing university is Universidade De Sao Paulo Usp. Other universities according to their performances are; Nottingham Trent University (3), University of Groningen (4), Wageningen University & Research (5), University College Cork (6), University of California, Davis (7), University of Connecticut (8).

6. Sensitivity Analysis

A two-stage sensitivity analysis was performed to verify the validity, robustness, and reliability of the proposed WENSLO-AROMAN models. In the first stage, changes in the λ and β values were examined. In the study, the λ and β parameters were taken as 0.5. Within the scope of the sensitivity analysis, the recommended model was examined for other scenarios created with a 0.1 increase in value. The results of the sensitivity analysis related to the change in the λ value are presented in Figure 2, while the results obtained for the change in the β value are given in Figure 3.

Figure 2. Ranking Changes for Alternatives by Changing λ Values

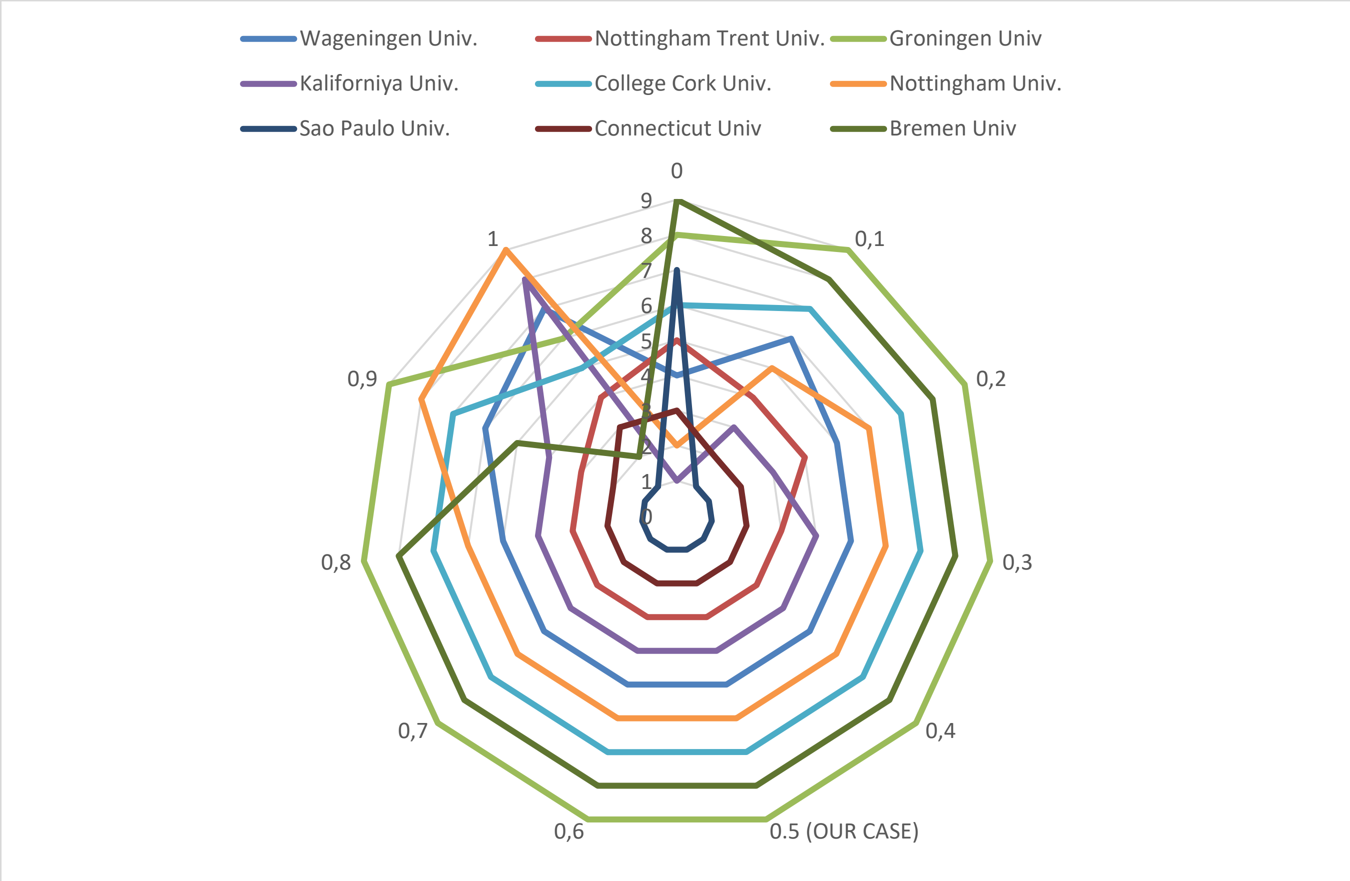
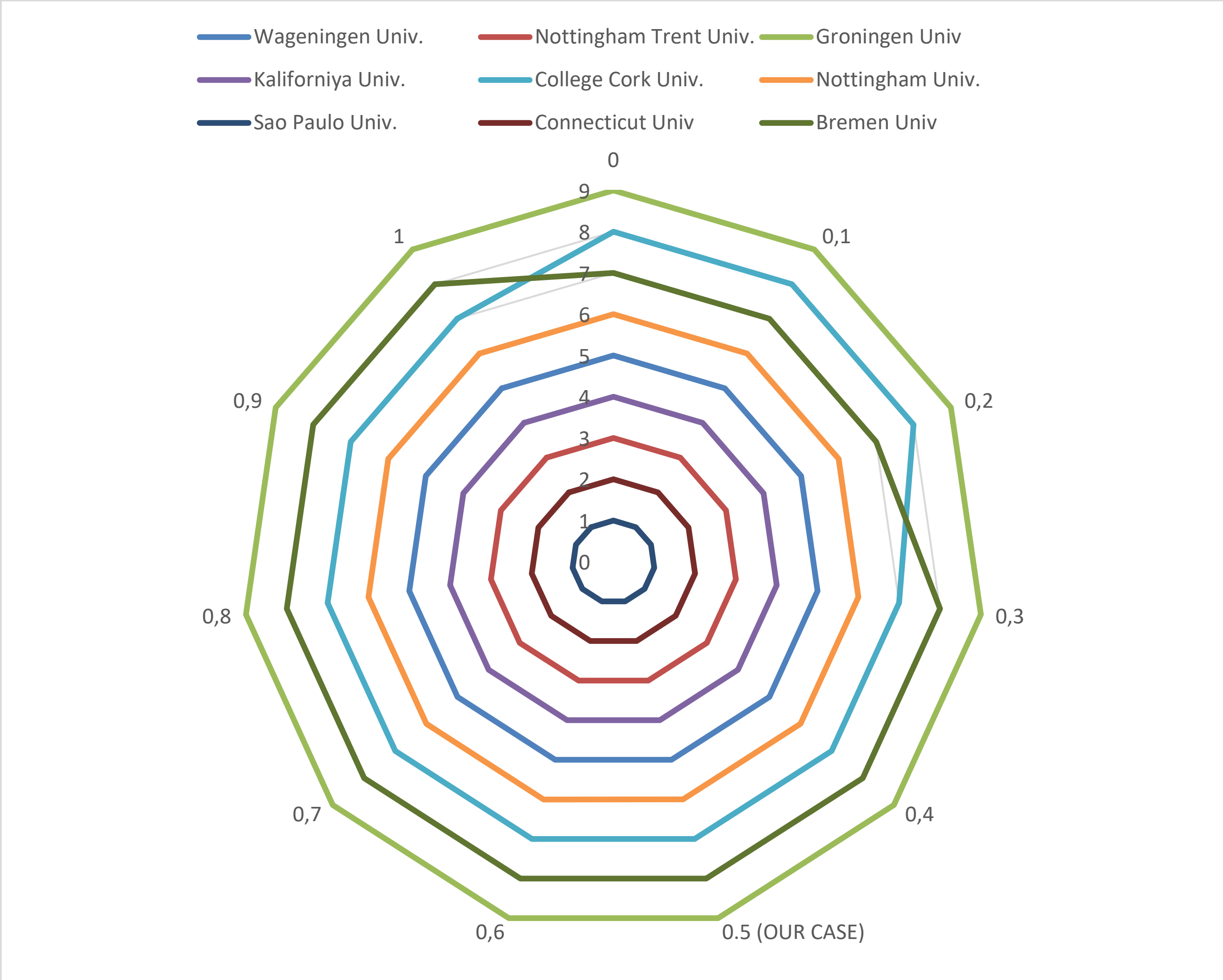
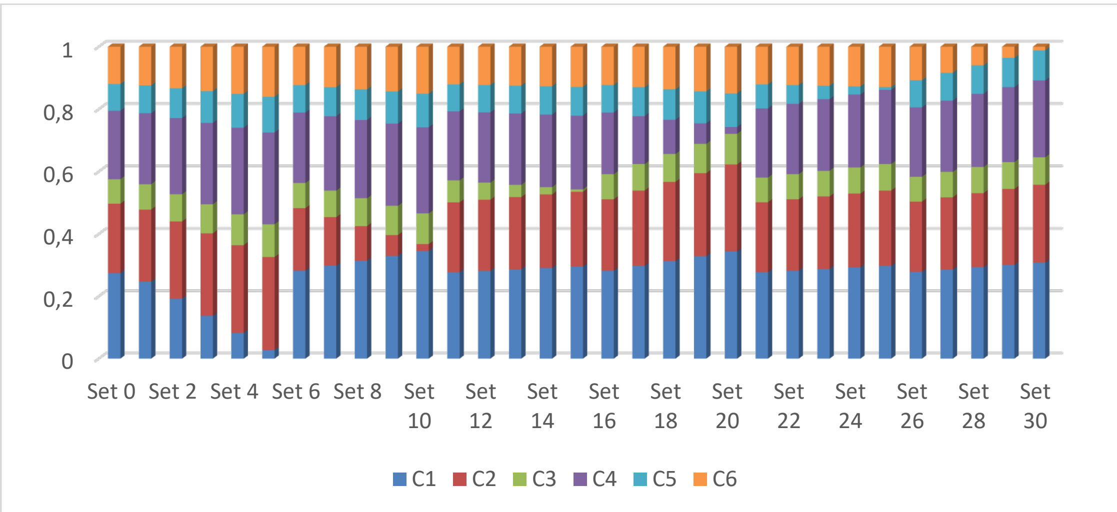


Figure 3. Ranking Changes for Alternatives by Changing β Values



Considering Figure 2, differences were observed in the ranking of alternatives in scenarios created according to changes in the λ value. These differences are particularly evident when λ takes the values 0, 0.1, 0.2, 0.9, and 1. In this context, the proposed model is sensitive to changes in the λ parameter. According to Figure 3, minor changes are observed in the ranking of alternatives in scenarios created based on changes in the β value. These minor changes appear in the ranking of College Cork and Bremen Universities in scenarios where β takes the values 0, 0.1, and 0.2. The proposed model has provided valid, robust, and reliable results except for very small changes in the β parameter. In the second stage, the effect of criterion weights on the ranking results of the WENSLO-AROMAN model was examined. For this purpose, 30 different scenarios were created and their graphical distribution is shown in Figure 4.

Figure 4. Different Sets for Criteria Weights

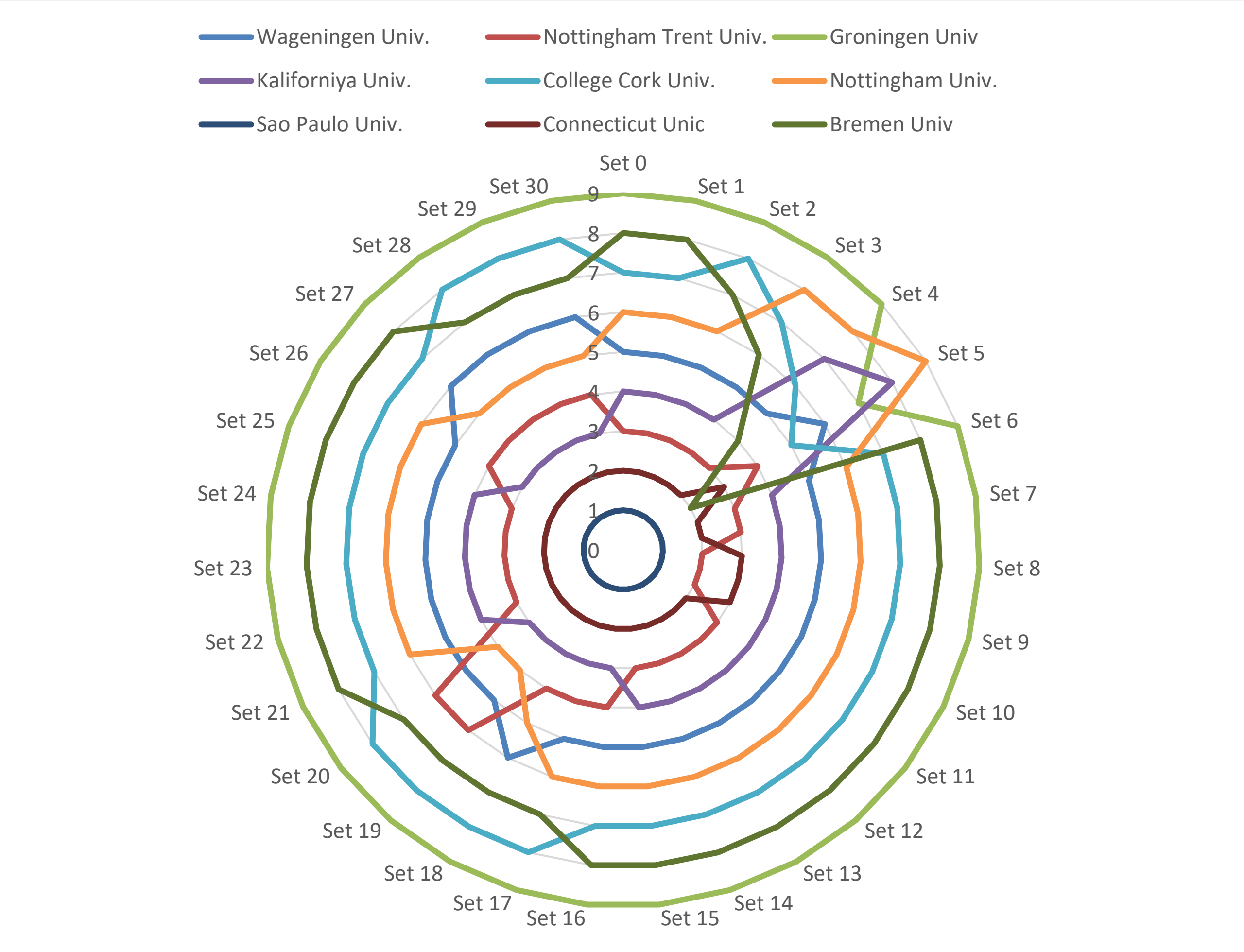


The current ranking results obtained using the model proposed in the first scenario, S0, are presented. The other scenarios (S1-S30) were created by reducing the relevant criterion weights by %10, %30, %50, %70 and %90. Equality (23) proposed by Ecer (2022) was used to create scenarios with new criterion weights.

$$w_{yad} = (1 - w_{ad})\left(\frac{w_{od}}{1 - w_{aod}}\right) \qquad (23)$$

Equality (23) shows the newly calculated weight values for the w_{yad} criterion, while w_{ad} represents the reduced (discounted) value of the criterion. In addition, the original value of the criterion is represented by w_{od}, while the original value of the criterion with the reduced (discounted) value is represented by w_{aod}. The results of the sensitivity analysis are presented in Figure 5.

Figure 5. Ranking changes for universities by changing criteria weights



Considering Figure 5, minor changes are observed in the ranking of alternatives in the scenarios created in response to changes in criterion weights, except for scenario 5. The proposed model is less sensitive to changes in criterion weights in the ranking of the first two and last universities and produces more consistent results. The University of Sao Paulo, which is in the first position, maintains its position in all scenarios, while the University of Connecticut, which is in the second position, has not changed its position except in scenarios 5, 8-10. The University of Groningen, which is in the last position, has maintained its position except in scenario 5. Overall, the proposed model is valid, robust, and reliable against changes in criterion weights, except for scenario 5, and is less sensitive.

As proposed by Ecer (2021) and Ecer et al. (2019), the ranking results of the proposed model and the 30 scenarios created using the proposed model were analysed using the Spearman rank correlation coefficient (SRCC). Except for scenario 5, all correlation coefficients are greater than 0.75, indicating a high correlation between the ranking results of the proposed model and the ranking results of the different scenarios. The results obtained from the SRCC reveal that changes in the weights in different scenarios do not significantly affect the final ranking of the proposed approach.

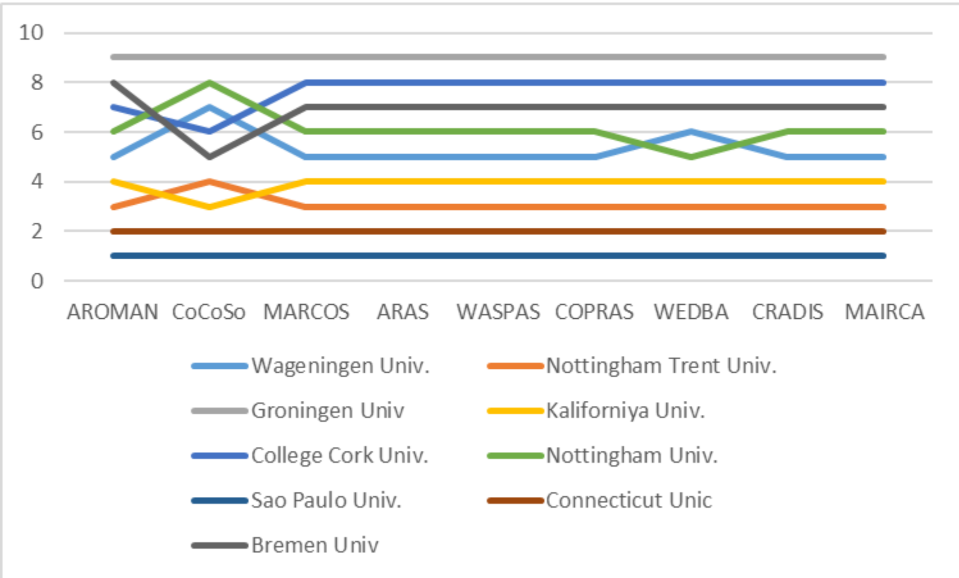
7. Comparison Analysis

In order to test the reliability of the ranking results obtained from the proposed WENSLO-AROMAN model, a comparison analysis was performed with other MCDM techniques such as AROMAN CoCoSO, MARCOS, ARAS, WASPAS, COPRAS, WEDBA, CRADIS and MAIRCA. The results of the comparison analysis within the scope of SRCC values are given in Table 21, while the ranking results related to the comparison analysis are presented in Figure 6.

Table 21. Spearman's rank correlation coefficient values related to the methods compared

	AROMAN	CoCoSo	MARCOS	ARAS	WASPAS	COPRAS	WEDBA	CRADIS	MAIRCA
AROMAN	1,0000								
CoCoSo	0,8333	1,0000							
MARCOS	0,9833	0,8500	1,0000						
ARAS	0,9833	0,8500	1,0000	1,0000					
WASPAS	0,9833	0,8500	1,0000	1,0000	1,0000				
COPRAS	0,9833	0,8500	1,0000	1,0000	1,0000	1,0000			
WEDBA	0,9667	0,8333	0,9833	0,9833	0,9833	0,9833	1,0000		
CRADIS	0,9833	0,8500	1,0000	1,0000	1,0000	1,0000	0,9833	1,0000	
MAIRCA	0,9833	0,8500	1,0000	1,0000	1,0000	1,0000	0,9833	1,0000	1,0000

Figure 6. Sustainable Universities ranking results with MCDM methods according to Green Metric Criteria



When the values in Table 21 are considered, the average SRCC value of the AROMAN method with other techniques is found to be 0.9625. According to the obtained SRCC values, a statistically significant (at 1%) and high correlation was found between the AROMAN method and other techniques. This situation shows the validity, applicability and reliability of the proposed model. In other words, the proposed WENSLO-AROMAN model provides consistent results when compared with other techniques.

Results and Discussion

With the increasing awareness of sustainability and environmental issues, the concept of sustainable universities has emerged. Universities are playing a growing role in sustainability, not just through the research they undertake but also by cultivating eco-friendly environments in their campus operations. The share of universities in sustainability is gradually increasing. The education received during the university education process is very important for societies to internalize and implement the concept of sustainability. In order for sustainability to spread to social life, it is expected that the practices and campus life of universities should be sustainable. For this reason, universities should determine and implement their strategies within the framework of the understanding of sustainability. Many systems have been proposed for the sustainability measurement of universities, and UI GreenMetric is one of them. The UI GreenMetric system ranks world universities with different quantitative and qualitative criteria and sub-criteria.

In this study, data obtained from the UI GreenMetric platform was examined in order to analyze the sustainability performance. A two-stage method was used for the performance ranking of sustainable universities. For numerical inference, the 2014-2023 data of the universities ranked in the top 10 according to the 2023 UI GreenMetric evaluation were used. The criteria were weighted with the WENSLO method and the alternatives were ranked with the AROMAN method. Umwelt-campus Birkenfeld

University (Germany) was not included in the study, because it was not part of the UI GreenMetric ranking in 2014 and the study was conducted with 9 universities. When the weights of the criteria were examined with the WENSLO method, it was concluded that the most important criteria were the location and infrastructure criteria. The AROMAN method revealed that the University of Nottingham had the highest performance.

This study makes the following contributions: 1- The criteria are weighted with the WENSLO objective weighting method. WENSLO is a newly used method in determining the weight coefficient of the criteria and offers the opportunity to examine the criteria behavior independently, away from randomness. 2- The study applied the AROMAN ranking method to establish alternative preferences. The AROMAN method takes into account multiple minimum and maximum structured criteria that are related to each other. 3- It is thought that the study results can contribute to universities by revealing the weights of the criteria they should give importance to on the way to sustainability.

The study is limited to 10-year data of 9 universities. It is possible to reach different results with different numbers of universities. WENSLO-AROMAN methodology is a powerful tool for objective decision making. However, uncertainty is neglected in the evaluation of alternatives. In future studies, applications examining uncertainty can be carried out. In future studies, a different ranking can be obtained by including different universities. Different MCDM problems can be analyzed with the methods used in the study. In addition, WENSLO and AROMAN methods can be combined with other MCDM methods and applications can be made.

Author Contributions

The author has not declared any other contributors.

Acknowledgments

The author(s) did not provide acknowledgment.

Funding and Support

The author(s) did not report any funding or support information.

Conflict of Interests

The author(s) did not report any conflict of interest.

Ethics Statement

The author(s) did not report ethical committee approval as the research content does not require.

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