Comparison of Fuzzy Clustering Algorithms on UI GreenMetric University Rankings

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Abstract: - That universities will supply remarkable assistance on the pathway to sustainability by providing intellectual leadership in attaining a sustainable society is an acceptable and emphasized issue. Herewith, in this work, we aimed to divide the campuses into homogeneous groups using fuzzy clustering techniques by employing the UI GreenMetric World University Rankings data having ranked the world's prestigious universities every year since 2010. In the results obtained, these universities are separated into four groups. Generalized possibilistic fuzzy clustering algorithm formed the most homogeneous clusters. Also, this algorithm clustered universities in a shortest time. While the "education and research" and "waste" categories are the strength aspect of the top green campuses, "water" is determined as the improvement aspect of the less sustainable campuses.

Key-Words: - Fuzzy C-Means, Possibilistic Fuzzy C-Means, Generalized possibilistic Fuzzy C-Means, Sustainability, GreenMetric, Clustering.

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1 Introduction

The terms “Sustainability” and its close counterpart “Sustainable Development” have been in the public space since the mid-80s when their original definitions were made. Yet the unique concept is “sustainable development”, it can be said that it is replaced by 'sustainability' at an increasing rate within the process. It can be stated that these concepts, which are clarified to have emerged from the environmental movement, reflect the acceptance that the main environmental problems are related to the economic and social justice issues [1].

The overscale definition of sustainable development is made in the form of 'development that preserves and improves the natural environment and social equality and includes economic and social development'. In this definition, all three dimensions of sustainable development are clearly included. Provided that the environment and social equality are protected and developed, it has been stated that all kinds of social and economic development are sustainable. Emphasizing the importance of ecological sustainability since the economy and society ultimately depend on the integrity of the biosphere and the ecological processes that develop within it, it is presented as a constraint on the varieties of economic and social development [2].

With the advancements in the communication and transportation technology, in today’s world becoming almost a “global village”, where globalization continues at full speed, the importance given to sustainability issue is increasing day by day. The notion of sustainability forms one of the most significant ideas for the 21st century on a social, global and humanistic level.

It is seen that in the second decade of the 21st century, an increasing number of universities and higher education institutions have adopted more responsible behaviors towards society and various stakeholders and have begun to follow the sustainable development agenda more closely due to its wide sphere of influence. Universities are no longer judged solely on the basis of their potential to provide quality education; including the community's commitment to progress, other criteria and factors play a role in reflecting the true image of the university [3]. In this manner, many educational

institutions commit to sustainable development as signatories of international declaration and declaration [4]. It is seen that the universities increasingly institutionalize sustainability practices within the scope of curriculum, research, activity, progress, evaluation and reporting [3]. Besides, it can be said that the concept has become one of the significant parameters of university ranking systems.
In this study, it is aimed to divide the campuses into homogeneous groups with the help of fuzzy clustering methods through the UI GreenMetric World University Rankings data, which evaluates higher education institutions according to six criteria and 39 indicators: infrastructure, recycling, energy and climate change, water resources, transportation and education [5].
The rest of the article is structured as follows. Section 2 explains fuzzy clustering techniques and GreenMetric Ranking indicators. Section 3 details results. Section 4 summarizes the main conclusions of the article.

2 Problem Formulation

Unsupervised learning is an important subsection of Machine Learning that deals with the problem of analyzing unlabeled data [6]. Among the various techniques in this domain, clustering methods are widely used for grouping unlabeled data. These methods are categorized based on the structure of their cluster assignments [7]. Studies have shown that fuzzy clustering methods are more flexible than hard clustering methods. In this work, we will apply fuzzy clustering techniques.

2.1 Fuzzy Clustering Techniques

2.1.1 Fuzzy C-Means and Possibilistic C-Means (FCM-PCM)

Fuzzy c-means (FCM) algorithm is the best known and widely used method among fuzzy division clustering techniques [8]. The fuzzy c-means method allows objects to belong to two or more clusters [9]. Fuzzy logic says that each data or object is connected to clusters with a membership value ranging from [0,1], and the sum of the membership values of a data or object to all classes must be “1”. Whichever cluster center the object is close to; the membership of that cluster will be larger than the membership of other clusters. The membership matrix, which is the most important feature of the fuzzy c-means algorithm, has positive effects on clustering. This matrix facilitates the identification of uncertain situations [9]. In addition, due to low membership degrees, the impact of extraordinary data is small. The ability of the FCM algorithm, which has a flexible structure, to find overlapping sets is higher than other divisional algorithms.
In addition to the advantages mentioned above, the fuzzy c-means algorithm also has some disadvantages. Since membership function increases computational complexity, it is a time-consuming divisional clustering algorithm. FCM is also an objective function-based method. The algorithm tries to minimize by shifting following objective function, which it implements as a generalization of the least squares method [10].
U membership matrix with fuzzy values reflects the clustering result. If necessary, these values obtained after clustering can be rounded to 0 and 1 by defuzzification. Not very good performance for noisy data is a disadvantage of the FCM algorithm. Possibilistic C-Means (PCM) have been introduced to cope with this disadvantage [11] but suffer from overlapping clusters [11].
The first step in Fuzzy C-Means is to determine the cluster center, which will mark the average position for each cluster. Under initial conditions, this cluster center is not yet accurate. Each data point has a membership degree for each cluster. By repeatedly fixing the center of the cluster and the membership degree of each data point, it will be seen that the center of the cluster will move to the correct position. This iteration is based on minimizing the objective function that defines the distance from a given data point to the center of the cluster, weighted by the membership degree of the data point [12]. The function of the FCM algorithm to find clusters with maximum purity is given by Eq. (1) [13].

$$J(U,V;X)=\sum_{j=1}^{N}\sum_{i=1}^{c}u_{ij}^{m}\left\|\vec{x}_j-\vec{v}_i\right\|_A^2,$$
$$\sum_{i=1}^{c}u_{ij}=1,\sum_{j=1}^{N}u_{ij}>0 \tag{1}$$

where N is number of data vectors, $c\in(1,N]$ is number of clusters, $\vec{v}_i$ is center of the i^{th} cluster, $\vec{x}_j$ is j^{th} data vector (j^{th} column of the data matrix $X_{r\times N}$), $m>1$ is degree of fuzziness, u_{ij} is membership grade of the j^{th} data vector in the i^{th} cluster, $\left\|\vec{x}_j-\vec{v}_i\right\|_A^2$is distance.
Partition matrix $U_{c\times N}$ and cluster centers matrix $V_{r\times c}$minimize Eq. (2) [13].

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$$u_{ij} = \left[\sum_{k=1}^{c}\left(\frac{\left\|\vec{x}_j-\vec{v}_i\right\|_A^2}{\left\|\vec{x}_j-\vec{v}_k\right\|_A^2}\right)^{\frac{1}{m-1}}\right]^{-1},$$
$$\vec{v}_i = \frac{\sum_{j=1}^{N} u_{ij}^m \vec{x}_j}{\sum_{j=1}^{N} u_{ij}^m} \tag{2}$$

PCM uses the objective function with c_FCM=0 in which cluster centers and typicalities t_ijs are calculated without considering u_ijs [14].

2.1.2 Fuzzy Possibilistic C-Means (FPCM)

The objective of FPCM model is to find by minimizing the Eq 3.

$$J_{m,n}(U,T,V) = \sum_{\mathrm{i}=1}^{c}\sum_{k=1}^{n}\left(\mu_{ik}^m + t_{ik}^\eta\right)\left\|\vec{x}_j - \vec{v}_i\right\|^2 \tag{3}$$

where $m > 1, \eta > 1, 0 \leq u_{ik}, t_{ik} \leq 1$.
The constraints that Fuzzy Possibilistic C-Means must satisfy as follows; $\sum_{\mathrm{i}=1}^{c}\mu_{ik} = 1, \sum_{k=1}^{n} t_{ik} = 1$.

2.1.3 Possibilistic Fuzzy C-Means (PFCM)

The PFCM algorithm that minimizes the objective function by crossing PCM and FCM is given by Eq. (4) [15].

$$J(U,T,V\,;X) = \sum_{k=1}^{N}\sum_{l=1}^{c}\left(c_{FCM}u_{lk}^m + c_{PCM}t_{lk}^\eta\right)\|\vec{x}_k - \vec{v}_l\|_A^2 + \sum_{l=1}^{c}\gamma_l\sum_{k=1}^{N}(1-t_{lk})^\eta,$$
$$\sum_{l=1}^{c}u_{lk} = 1, \sum_{k=1}^{N}u_{lk} > 0 \tag{4}$$

where $c_{FCM} \geq 0$ and $c_{PCM} \geq 0$ refer membership grade u_{lk} and typicality t_{lk} and η is a number as m [15].
Euclidean distance norm compliance is the major issue with FCM, PCM, FPCM and PFCM. Ellipsoidal sets consist of the covariance norm that better fits with the patterns and structures of the data. Euclidean distance measure is not suitable when data rows have different types of units, but covariance gives non- dimension distance and could be used.

2.1.4 Generalized Possibilistic Fuzzy C-Means (GPFCM)

The function of the GPFCM with constraints is given by Eq. (5) and optimized [16].

$$J(U,T,V\,;X) = \sum_{j=1}^{N}\sum_{i=1}^{c}\left(c_{FCM}u_{ij}^m f_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right) + c_{PCM}t_{ij}^\eta f_{i,PCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right)\right) + \sum_{i=1}^{c}\gamma_i\sum_{j=1}^{N}\left(1-t_{ij}\right)^\eta,$$
$$\sum_{i=1}^{c}u_{ij} = f_j, \sum_{j=1}^{N}u_{ij} > 0 \tag{5}$$

Eq. 5 is optimized through Lagrange Multipliers.

$$J^*(U,T,V\,;X) = \sum_{j=1}^{N}\sum_{i=1}^{c}\left(c_{FCM}u_{ij}^m f_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right) + c_{PCM}t_{ij}^\eta f_{i,PCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right)\right) + + \sum_{i=1}^{c}\gamma_i\sum_{j=1}^{N}\left(1-t_{ij}\right)^\eta + \sum_{j=1}^{N}\lambda_j\left(\sum_{i=1}^{c}u_{ij} - f_j\right) \tag{6}$$

Centroids are calculated as Eq 7.

$$\frac{\partial J^*(U,T,V\,;X)}{\partial \vec{v}_i} = \sum_{j=1}^{N}\left(c_{FCM}u_{ij}^m f'_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right) + c_{PCM}t_{ij}^\eta f'_{i,PCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right)\right)(A + A^T)\left(\vec{x}_j - \vec{v}_i\right) = 0$$

$$\vec{v}_i^{z+1} = \frac{\sum_{j=1}^{N}\left(c_{FCM}u_{ij}^m f'_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i^z\right\|_A^2\right) + c_{PCM}t_{ij}^\eta f'_{i,PCM}\left(\left\|\vec{x}_j-\vec{v}_i^z\right\|_A^2\right)\right)\vec{x}_j}{\sum_{j=1}^{N}\left(c_{FCM}u_{ij}^m f'_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i^z\right\|_A^2\right) + c_{PCM}t_{ij}^\eta f'_{i,PCM}\left(\left\|\vec{x}_j-\vec{v}_i^z\right\|_A^2\right)\right)} \tag{7}$$

The algorithm converges when $\left\|U^{(z+1)} - U^{(z)}\right\| \leq \varepsilon$ where z refers iteration number and ε is a threshold [16]. u_{ij} is calculated by Eq. (8):

$$\frac{\partial J^*(U,T,V\,;X)}{\partial u_{ij}} = c_{FCM}mu_{ij}^{m-1}f_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right) + \lambda_j = 0$$
$$\Rightarrow u_{ij} = \left(\frac{-\lambda_j}{c_{FCM}mf_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right)}\right)^{\frac{1}{m-1}},$$
$$\sum_{k=1}^{c}u_{kj} = f_j \Rightarrow$$
$$u_{ij} = \left[\sum_{k=1}^{c}\left(\frac{f_{i,FCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right)}{f_{k,FCM}\left(\left\|\vec{x}_j-\vec{v}_k\right\|_A^2\right)}\right)^{\frac{1}{m-1}}\right]^{-1} f_j \tag{8}$$

And for the typicality t_{ij} is calculated by Eq. (9);

$$\frac{\partial J^*(U,T,V\,;X)}{\partial t_{ij}} = c_{PCM}\eta t_{ij}^{\eta-1}f_{i,PCM}\left(\left\|\vec{x}_j-\vec{v}_i\right\|_A^2\right) - \gamma_i\eta\left(1-t_{ij}\right)^{\eta-1} = 0$$

$$\Rightarrow$$
$$t_{ij} = \left(1 + \left(\frac{c_{PCM}}{\gamma_i} f_{i,PCM}\left(\left\|\vec{x}_j - \vec{v}_i\right\|_A^2\right)\right)^{\frac{1}{\eta-1}}\right)^{-1},$$
$$\gamma_i = K \frac{\sum_{j=1}^{N} u_{ij}^m \left\|\vec{x}_j - \vec{v}_i\right\|_A^2}{\sum_{j=1}^{N} u_{ij}^m} \qquad (9)$$

γ_is, U and V are calculated using PFCM to initialize GPFCM [16].

2.2 UI GreenMetric

The sustainability ranking designed by the University of Indonesia and put into practice in 2010 is the Universitas Indonesia GreenMetric World University Rankings. This ranking is accepted as the first and only global assessment tool for sustainability. With the UI GreenMetric WUR, it is aimed to evaluate the policies and activities of green campuses to promote a culture of sustainability in universities. In this direction, criteria have been created in some headings to measure universities in terms of sustainability. The fact that the ranking is suitable for universities in developed and developing countries is the reason why it is considered as a global ranking system [17]. In addition to measuring universities' efforts to improve the sustainability of their different campuses, one of the main purposes of the UI GreenMetric World University Rankings is to provide a comparative tool for assessing campus sustainability worldwide [18]. GreenMetric has identified 6 categories for the evaluation of universities based on certain criteria considered important in sustainability issues [19]. Each category and their specific weights are shown in Fig.1

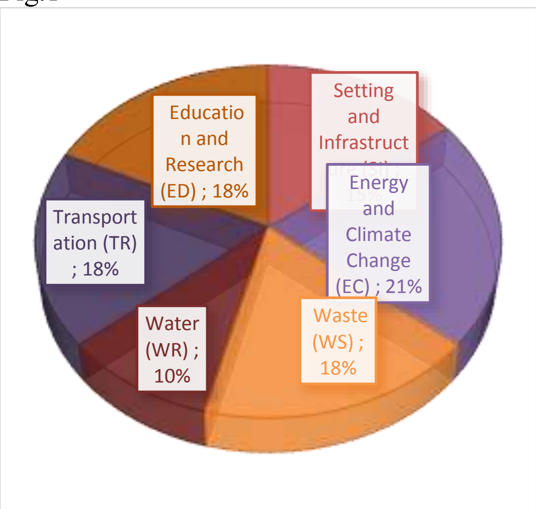

Figure 1. UI GreenMetric Category

The number of universities participating in the rankings has seen a steep increase over the years, from 95 universities in 35 countries in 2010 to 956 universities in 80 countries in 2021 [20].

3 Problem Solution

The Sustainable Development Goals aim to generate global action for the implementation of the 2030 Agenda for Sustainable Development [21], and the international rankings for Sustainable Development provide a baseline, list areas of strength and identify needs and areas for improvement [22]. In this context, this study seeks to address the hypothesis of whether it is possible to group universities according to their environmental sustainability performance by utilizing the GreenMetric ranking, an international ranking.

At this stage, a different fuzzy clustering algorithm was applied to group the different universities into homogeneous groups. We used the 2021 UI GreenMetric World Rankings for Universities as a data set. The application carried out within the scope of the study was developed in the MATLAB R2021b version. Codes were created for FCM, FPCM, PFCM and GPFCM algorithms. All algorithms were applied within the framework of the same parameters (initial value, stopping criterion, etc.). In terms of ease of operation, the Fuzzifier parameter (m) is preferred as 2. The initialization of the typicality matrix T is randomly generated. First, the FCM algorithm was run. The reason for this is to avoid random assignment of the initial U-matrix in the other algorithm. According to the result of the membership matrix of FCM, FPCM, PFCM and GPFCM algorithms were run respectively. In addition, Separation and Partition validity indices were used to select the optimal number of clusters for the four algorithms. Separation and Partition indices are objective methods that comprehensively evaluate clustering quality, provide comparability between algorithms and are suitable for fuzzy clustering. These indices, which are widely used in literature, aim to increase the reliability of the study.

Separation Index (S): Separation index directly measures the magnitude of gap between pair of clusters is easy to compute and interpret and hast the scale equivariance property [23].

Partition Index (SC): By this measure, good clustering results in homogeneity within each cluster and heterogeneity between clusters. Variability in clusters is measured by distance calculation. Internal variability is determined by taking the mean distance between each pair of data in the cluster and then the average across all clusters. The distance between clusters is obtained by averaging all pairwise distances between clusters. [23].

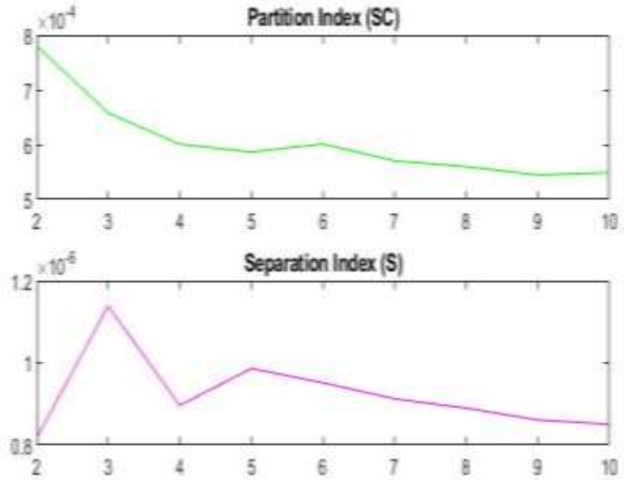

Figure 2.Optimal number of clusters by using validity indices

Obtained results are shown on Fig.2. The optimal number of clusters was taken as 4**.** These 4 clusters can be classified as follows:

- Cluster 1: "Low Sustainable Universities"
- Cluster 2: "Middle Sustainable universities"
- Cluster 3: "High Sustainable universities"
- Cluster 4: "Top Sustainable universities"

Table 1.Cluster size for all algorithms

	Cluster1	Cluster2	Cluster3	Cluster4
FCM	177	272	243	264
PCM	956	0	0	0
FPCM	232	237	229	258
PFCM	220	91	348	297
GPFCM	177	272	243	264

Applying the FCM and the improved algorithm GPFCM procedure, we obtained four clusters of very similar size. Since the PCM algorithm collects all the data in a single cluster, it could not make the correct classification.

Table 2.Comparison of algorithms according to calculation time and number of iterations

Algorithms	Comp. Time	İteration
FCM	6,78	93
PCM	34,25	205
FPCM	98,61	100
PFCM	8,75	94
GPFCM	0,33	100

Although the GPFCM algorithm obtained clusters like the FCM algorithm, much better results have been obtained from the FCM algorithm in terms of iteration and computation time.

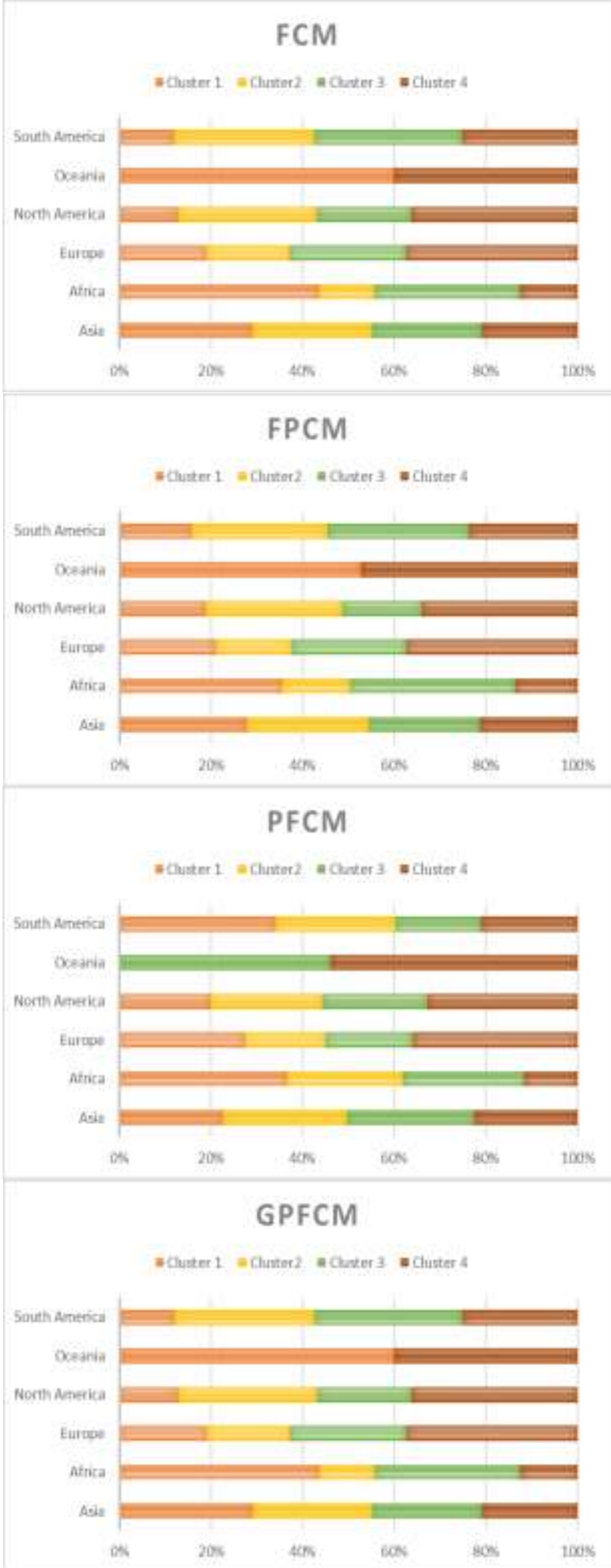

Figure 3. Distribution of universities by Region

Although FCM and GPFCM algorithm obtained almost the same clusters, the GPFCM algorithm was completed in a much shorter time than all other algorithms. The mean value calculated for each category was found to provide within-group homogeneity in GPFCM and FCM algorithms. In other words, the correct application of GPFCM and

FCM in the groups obtained because of clustering resulted in low variability.

Table 3. Descriptive statistics of clusters obtained by all algorithms

			FCM	FPCM	PFCM	GPFCM
Cluster 1	SI	Mean	542,66	574,03	879,66	542,66
		Std. Dev.	223,45	227,59	201,03	227,28
	EC	Mean	546,89	571,77	1027,73	546,89
		Std. Dev.	249,30	267,13	283,96	262,59
	WS	Mean	416,95	484,91	1111,70	416,95
		Std. Dev.	264,16	296,23	268,18	255,57
	WR	Mean	260,17	287,72	610,68	260,17
		Std. Dev.	160,52	163,93	167,68	163,36
	TR	Mean	549,58	607,11	1153,18	549,58
		Std. Dev.	273,92	281,39	229,82	254,86
	ED	Mean	548,59	624,68	1202,50	548,59
		Std. Dev.	304,90	318,76	227,77	273,34
Cluster 2	SI	Mean	786,21	814,35	832,97	786,21
		Std. Dev.	183,05	172,33	153,70	183,56
	EC	Mean	752,21	788,61	878,85	752,21
		Std. Dev.	247,79	247,62	214,70	247,55
	WS	Mean	788,60	827,22	875,27	788,60
		Std. Dev.	260,12	254,94	228,32	259,65
	WR	Mean	465,44	492,19	537,36	465,44
		Std. Dev.	156,04	160,88	134,49	156,71
	TR	Mean	931,43	974,89	1008,52	931,43
		Std. Dev.	233,02	208,63	174,61	232,68
	ED	Mean	965,35	1001,37	1046,70	965,35
		Std. Dev.	248,23	226,08	195,19	248,27
Cluster 3	SI	Mean	896,30	907,21	648,35	896,30
		Std. Dev.	197,06	193,49	234,76	196,99
	EC	Mean	1078,1	1093,45	621,62	1078,09
		Std. Dev.	256,17	243,02	260,74	255,66
	WS	Mean	1107,1	1122,05	567,03	1107,10
		Std. Dev.	250,71	245,99	294,37	250,34
	WR	Mean	629,84	640,39	342,39	629,84
		Std. Dev.	157,89	150,86	177,74	158,91
	TR	Mean	1191,8	1203,82	718,89	1191,77
		Std. Dev.	213,81	207,24	303,53	214,29
	ED	Mean	1226,4	1239,74	722,13	1226,44
		Std. Dev.	221,34	212,90	310,95	221,35
Cluster 4	SI	Mean	1083,5	1084,59	1073,40	1083,52
		Std. Dev.	174,64	175,87	175,17	174,64
	EC	Mean	1394,1	1401,07	1377,19	1394,13
		Std. Dev.	235,97	230,73	230,72	235,97
	WS	Mean	1457,4	1459,59	1415,91	1457,39
		Std. Dev.	233,30	230,44	248,66	233,30
	WR	Mean	813,07	815,12	801,18	813,07
		Std. Dev.	132,36	131,45	134,97	132,36
	TR	Mean	1384,4	1388,08	1380,64	1384,38
		Std. Dev.	171,19	169,32	165,15	171,19
	ED	Mean	1523,8	1526,45	1511,36	1523,77
		Std. Dev.	159,97	159,05	160,48	159,97

Table 3 shows the basic statistics of different groups and clusters by all algorithms. According to the results of all algorithms, universities in the 4th cluster (i.e., high sustainability level) with high values in the Waste, Education and Research categories, while the universities in the 1st cluster have lowest values in the water treatment category. In this context, these results can be a useful indicator for improving the ranking of universities and investing in these categories.

4 Conclusion

In this study, both the comparison of fuzzy clustering algorithms and the current sustainability levels of universities are revealed. In addition, it aims to reveal the aspects that are open to development in terms of sustainability and to contribute to universities. This article compares fuzzy clustering methods to divide the campuses into homogeneous groups based on the UI GreenMetric World University Ranking data. In this context, we used the UI GreenMetric 2021 as a dataset. This analysis allowed us to identify four levels of sustainability campuses: top, high, medium, and low green.

It can be said that PCM clustering analysis occurred an artificial cluster as all data is associated in a cluster. It can also be said that the classification based on fuzzy c-means and generalized fuzzy possibilistic c means algorithm reflects the natural classification resulting from the combination of variables in the data matrix.

Generalized fuzzy possibilistic c- means algorithm worked in harmony with the validity indices and clustered the data in an optimal computation time than other basic algorithms. Thus, we have saved time.

It revealed that in universities with the least sensitivity to sustainability, the category of the treatment of water and waste was seen as open to improvement. On the other hand, higher and medium-high universities (the most stable) managed to score maximum points in the treatment of water and waste, as well as in the research and education aspects. We offer some suggestions to support the improvement of activities of universities that are less successful in water and waste areas.

- “Sustainability Advisory Center” can be established where guidance on water treatment and waste management can be provided through best practices.
- Sensor-based systems that can monitor water consumption on campus in real time can be installed and interventions can be made to prevent water waste.
- Rainwater collection systems can be installed on university campuses and recycled water can be used for needs such as irrigation and cleaning.
- Separation bins can be placed throughout the campus to include paper, plastic, glass and organic waste in recycling processes.
- Reusable products can be preferred over single-use products, for example by distributing refillable water bottles to students and employees.
- Collaborations could be established with successful universities in the UI GreenMetric rankings to encourage the sharing of good practices in these areas.

It is thought that this study will bring transparency in terms of creating a more social awareness of sustainability and a model for the Universities that are left behind.

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