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Forecasting sustainable development level of selected Asian countries using M-EDAS and k-NN algorithm

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Abstract

This study aims to forecast the sustainable development levels of countries with the fewest possible parameters based on social, economic, and environmental dimensions. For this purpose, a hybrid model consisting of multi-criteria decision-making and machine learning methods is proposed. First, using the M-EDAS method, selected Asian countries were ranked based on the main goals of the Sustainable Development Report. Based on ranking findings, sustainability development levels were determined for 2017–2020. Using the last two years before the relevant year as a training dataset, the sustainable development levels determined for 2019-2020 were estimated based on two basic macroeconomic variables. However, the forecast findings of 2020 were not as successful as those for 2019. Additionally, the findings obtained from the ranking analysis were evaluated using Spearman's correlation to compare the periods before and during the COVID-19 pandemic.

1. Introduction

Nations face significant challenges as their social, economic, and environmental resources deteriorate or become depleted. These resources are interconnected, and for this reason, there are no simple solutions to the problems caused by the nation. It has been suggested that many indicators reflect the three main components of sustainable development (Pereira et al., 2022: 1). Many scientists are researching sustainable development concerning the United Nations Sustainable Development Goals (Skvarciany et al., 2020). Seventeen goals have been made public and address the three sustainability pillars of no poverty, no hunger, ideal economic growth, high standards of education, decent work, and gender equality.

Between five and twelve targets are listed for each sustainable development goal, and approximately 303 indicators are suggested to help track progress toward the goals and targets (Hák et al., 2016: 569). Nonetheless, various researchers have specified that social and economic pillars should be analyzed in a relationship. Therefore, we examined these two pillars to explore sustainable socioeconomic development. A set of socioeconomic and natural environmental factors in any area determine sustainable development. Inequality and disruption in the development process result from not considering these factors (Gorbenkova et al., 2018: 786).

2. Literature review

Skvarciany et al. (2020) ranked countries based on sustainable development goals using an Evaluation Based on Distance from Average Solution (EDAS) multi-criteria decision-making method, followed by hierarchical cluster analysis to divide countries into groups based on sustainable socioeconomic development criteria. MCDM has

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*** All responsibility belongs to the researchers. All parties were involved in the research of their own free will. Ethics committee approval is not required as this study did not collect data on humans using experiments, methods, practices, etc.*

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been used to solve decision-making problems in various areas, such as economics and engineering, to rank alternatives from worst to best to make accurate decisions (Mutlu & Sarı, 2017; Ondrus et al., 2015; Torkayesh & Torkayesh, 2021). TOPSIS, CoCoSo, ELECTRE, and EDAS, which are examples of MCDM, have been used in some studies to rank countries and country groups, such as the European Union, G-20 (Ayan et al., 2017; Baral et al., 2014; Candan & Cengiz Toklu, 2022; Ela & Soysal Kurt, 2019; Pereira et al., 2022; Skvarciany et al., 2020; Skvarciany et al., 2021). Stanujkic et al. (2020) apply a hybrid model based on one of the MCDM methods and the Shannon Entropy method to rank the European Union countries relative to the sustainable development goals, and their gained findings imply that the applied model is appropriate for this type of analysis.

This study aims to predict a country's sustainable development level based on basic economic indicators. Because of the existence of different grouping systems for countries with different types of indicators, it becomes difficult to predict their belonging groups, which indicates the difficulty in predicting their level. As stated in the Sustainable Development Agenda, too many indicators influence the level of sustainable development (Colglazier, 2015). The group belonging to any country can be identified with the help of widely used indicators. Our assumption is to estimate the same belonging group, which refers to the same level of sustainability as the fundamental economic indicators such as inflation and GDP. To prove this assumption, the first step is to determine the belonging groups of the countries. Owing to its ease of use and minimal computing requirements (Ecer, 2018: 616), the EDAS method was used to determine the level of sustainable development, and the k-NN classifier was used to make the predictions. The study sample consists of selected Asian countries. The reason for our focus on 13 Asian countries is the degree of the spread of COVID-19 and therefore offers a superb opportunity to test the prediction of the sustainable development level. These countries encompass and symbolize enormous, well-known socioeconomic, demographic, geographic, environmental, and epidemiological variations. The methodology and dataset of the study are described in Section 2, along with a brief explanation of the techniques employed. Section 3 presents the applications and findings. The discussion section examines the findings, discusses the limitations of the study, and explains potential future studies.

3. Data and methodology

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Table 1. Evaluation criteria

Symbols	Definition	Sustainable Development Goal (SDG)	Target
C_1	Property Rights	SDG 1: No poverty, SDG 2: No hunger, SDG 3: Good health and well-being, SDG 5: Gender equality	Max
C_2	Judicial Effectiveness	SDG 16: Peace, justice, and strong institutions	Max
C_3	Fiscal Health	SDG 3: Good health and well-being	Max
C_4	Labor Freedom	SDG 8: Take immediate and effective measures to eradicate force labor	Max
C_5	Financial Freedom	SDG 16: Peace, justice, and strong institutions	Max
C_6	Communications, Computer, etc. (% of service imports, BoP)	SDG 9: Industry, innovation, and infrastructure	Max
C_7	GDP Per Capita Growth (annual %)	SDG 8: Decent work and economic growth	Max
C_8	Gross National Expenditure (% of GDP)	SDG 12: Responsible consumption and production	Max
C_9	High-technology Exports (% of manufactured exports)	SDG 9: Industry, innovation, and infrastructure	Max
C_{10}	Inflation, GDP deflator (annual %)	SDG 8: Decent work and economic growth	Max
C_{11}	Secure Internet Servers	SDG 9: Industry, innovation, and infrastructure	Max
C_{12}	Unemployment, total (% of total labor force) (modeled ILO estimate)	SDG 1: No poverty	Min
C_{13}	Women Business and the Law Index Score (Scale 1-100)	SDG 5: Promote gender equality and empower women	Max

Source: World Bank Data Center, heritage.org[1]
([1]https://s3.amazonaws.com/sustainabledevelopment.report/2020/europe_sustainable_development_report_2020.pdf)

In this study, we selected 13 Asian countries in different parts of the region. These countries include China, Hong Kong, India, Indonesia, Japan, Kazakhstan, Malaysia, Pakistan, the Philippines, Singapore, Thailand, Turkey, and Uzbekistan. The socioeconomic parameters used as evaluation criteria for ranking and grouping these

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countries are listed in Table 1. The major rationale for choosing the indicators listed in Table 1 is that they accurately depict the core of the aims and sub-aims of sustainable development.

The statistical methods employed in this study are divided into three parts: first, the importance level of each criterion is evaluated with the help of entropy and the critic method; second, the modified EDAS (M-EDAS) method is used to rank the countries for the years 2017, 2018, 2019, and 2020. The findings of these analyses were validated by comparing the periods before and during the COVID-19 pandemic using Spearman's correlation coefficient. In this section, we also group the selected Asian countries into four main groups based on their ranking: Very High, High, Medium, and Low. In the third part, the k-NN algorithm has been estimated to explore the specific groups of each country for 2019 and 2020.

3.1. Weight calculation methods

Selecting an appropriate statistical weighting method to address a Multiple Criteria Decision Making (MCDM) problems is of paramount importance due to its potential to yield unpredictable outcomes (Singh & Pant, 2021). There exist several subjective and objective approaches for determining the weights. Subjective weighting relies on the expertise and judgment of the decision-maker, whereas objective weighting is based on quantitative computation (Wang & Lee, 2009). The critic and entropy methods stand out as the most widely utilized techniques for determining objective weights (Abdel-Basset & Mohamed, 2020; Yazdani et al., 2020). In this study, we employed these methods to compute the weights for each criterion and subsequently compared them using equal importance levels, thereby facilitating the selection of the preferred method. The critic method, proposed by Diakoulaki et al. (1995), incorporates standard deviation and correlation analysis. The following section describes the calculation steps involved in the critic method (Krishnan et al., 2021):

1. Normalize the decision matrix.
2. Compute the standard deviation of each criterion.
3. Compute the correlation between the criteria.
4. Compute the information content.
5. Identify the objective weights (importance levels of each criterion)

Shannon's entropy method (Shannon & Weaver, 1947) is a well-known method for determining weights in an MCDM problem, particularly when finding a suitable weight based on preferences is impossible (Lotfi & Fallahnejad, 2010: 55).

The following is a description of the entropy method's calculating steps (Sun & Yu, 2021: 563):

1: $r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_i}$, where $i \in \{1,2,..,m\}$ and $j \in \{1,2,..,n\}$. (1)

2: $e_j = \frac{-1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln(r_{ij})$, where $i \in \{1,2,..,m\}$ and $j \in \{1,2,..,n\}$. (2)

3: $w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)}$, where $j \in \{1,2,..,n\}$. (3)

3.2. Modified EDAS (M-EDAS) Method

In 2015, Keshavarz Ghorabaee, Zavadskas, Olfat, and Turskis proposed the EDAS method. The following are the steps of the method (Keshavarz-Ghorabaee et al., 2015).

1: Choose the most appropriate criteria that describe all alternatives based on the decision problem.

2: Construct the decision matrix with the help of the information in Step 1.

3: Determine the average solution according to all criteria.

4: Compute the positive/negative distance from average (PDA/NDA) matrix according to the type of criteria (benefit and cost)

5: Determine the weighted sum of PDA and NDA for all alternatives

6: Normalize the values of the weighted sum of PDA and the weighted sum of NDA for all alternatives

7: Compute the average of normalized values in Step 6 and named as appraisal score (AS)

8: Rank the alternatives according to the decreasing values of AS.

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There are many interdisciplinary studies conducted with the EDAS method (Aggarwal et al., 2018; Almulhim, 2019; Behzad et al., 2020; Ecer, 2018; Feng et al., 2018; Keshavarz-Ghorabaee et al., 2016; Kahraman et al., 2017; Ren et al., 2021). In recent years, a large number of modifications of MCDM methods have been designed. In addition, a vast number of EDAS method modifications have been developed (Ilieva et al., 2018; Keshavarz-Ghorabaee, 2021; Ghalehno, 2021, Zavadskas et al., 2019). In this study, the modified version of the EDAS method, which has a significant influence on outlier data has been used. The steps of the M-EDAS are described as follows (Ghalehno, 2021: 99):

1: Calculate the average ($\bar{x}$) and variance (σ_x^2) of recorded data for each criterion.

2: Calculate the positive/negative distance from the mean (PD/ND):

$$PD_{ij} = \frac{0.341 \times max_i(0; \min(x_{ij} - \bar{x}; \sigma_x^2))}{\bar{x}} + \frac{0.136 \times max_i(0; \min(x_{ij} - \bar{x} - \sigma_x^2; \sigma_x^2))}{\bar{x}} + \frac{0.023 \times max_i(0; x_{ij} - \bar{x} - 2\sigma_x^2)}{\bar{x}} \quad (4)$$

$$ND_{ij} = \frac{0.341 \times max_i(0; \min(\bar{x} - x_{ij}; \sigma_x^2))}{\bar{x}} + \frac{0.136 \times max_i(0; \min(\bar{x} - x_{ij} - \sigma_x^2; \sigma_x^2))}{\bar{x}} + \frac{0.023 \times max_i(0; \bar{x} - x_{ij} - 2\sigma_x^2)}{\bar{x}} \quad (5)$$

3: Weight is assigned to PD and ND:

$$SP_i = \sum_{j=1}^{m} w_j PD_{ij}, \; SN_i = \sum_{j=1}^{m} w_j ND_{ij} \quad (6)$$

4: Normalize the values calculated in Step 3.

$$NSP_i = \frac{SP_i}{\max_i SP_i}, \quad NSN_i = 1 - \frac{SN_i}{\max_i SN_i} \quad (7)$$

5: The AS for all alternatives is calculated by taking the average of values calculated in Step 4.

$$AS_i = \frac{(NSP_i + NSN_i)}{2} \quad (8)$$

Finally, the alternatives are ranked by decreasing AS_i values, the alternative with the highest AS value being the best choice among the other alternatives.

3.3 K-NN algorithm

The k-NN algorithm is one of the simplest classifiers that has been used in different applications and k plays a crucial role in the accuracy of the algorithm (Tharwat et al., 2018). It predicts the category of the test sample based on the k training samples that are the test sample's nearest neighbors and assigns it to the category with the highest category probability (Choudhary et al., 2013). The steps of the process are as follows (Bhuvaneswari & Therese, 2015: 436):

1: Identify the value for k.

2: Determine the distance between the test sample and all the training samples.

3: Sort the distance

4: Select the k-nearest neighborhood

5: Compile the category of nearest neighbor

6: Apply the simple majority rule

The k-NN algorithm can be easily applied to various fields such as agriculture, finance, medicine, and engineering (Alkhatib et al., 2013; Huda & Chowanda, 2021; Mukid et al., 2018; Pacheco & Lopez, 2019; Ramteke & Monali, 2012; Shaw et al., 2021; Xing &Yilin, 2017).

This algorithm has some limitations such as the wrong choice of the distance or the value of k degrades the performance (Cherif, 2018). In other words, the chosen distance function can affect the classification accuracy. Euclidean and Manhattan distances are the most commonly used. In other words, the k-NN algorithm relies on a neighborhood of close patterns relative to a query pattern, and an important challenge is to find the best distance or similarity measure (Mehta et al., 2018, as cited in Ehsani & Drabløs, 2020). Hassanat proposed an intriguing distance metric that is invariant across scales in multidimensional data (Hassanat, 2014). Since the experimental results show that, when compared to some other well-known metrics, the proposed metric is a promising distance measure for the k-NN classifier with a high potential for a wide range of applications, we decided to apply Hassanat distance. This non-convex distance is calculated as follows (Hassanat, 2014):

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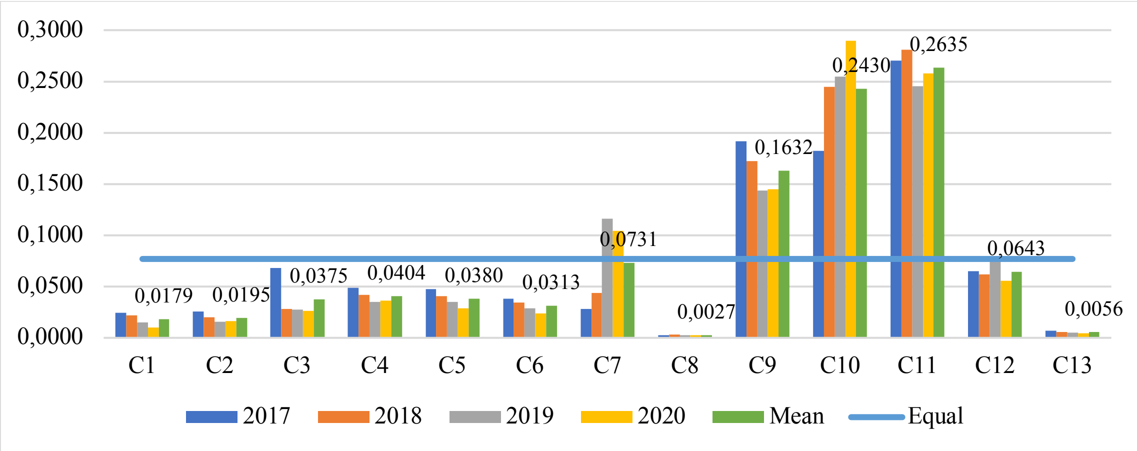
$$d_{Hassanat} = \sum_{i=1}^{n} D(x_i, y_i), \text{ where } D(x_i, y_i) = \begin{cases} 1 - \frac{1+\min(x_i,y_i)}{1+\max(x_i,y_i)} & , \min(x_i, y_i) \geq 0 \\ 1 - \frac{1+\min(x_i,y_i)+|\min(x_i,y_i)|}{1+\max(x_i,y_i)+|\min(x_i,y_i)|} & otherwise \end{cases} \quad (9)$$

4. Application

To prioritize the countries using the M-EDAS method, the first step is to select the most appropriate criteria that describe all the alternatives. The criteria used are listed in Table 1. The importance level of each criterion is then calculated. Because different results can be obtained for different degrees of importance, we calculated the degrees of importance of the criteria using the methods frequently used in the literature before deciding on the degree of importance of the criteria. The weights of each criterion obtained by the entropy method are illustrated in Figure 1, and the average value of each criterion for the years between 2017 and 2020 was also added to Figure 1 to make a comparison with equal distribution. Because C_{10} and C_{11} had the highest values, they were the most important criteria based on the entropy method.

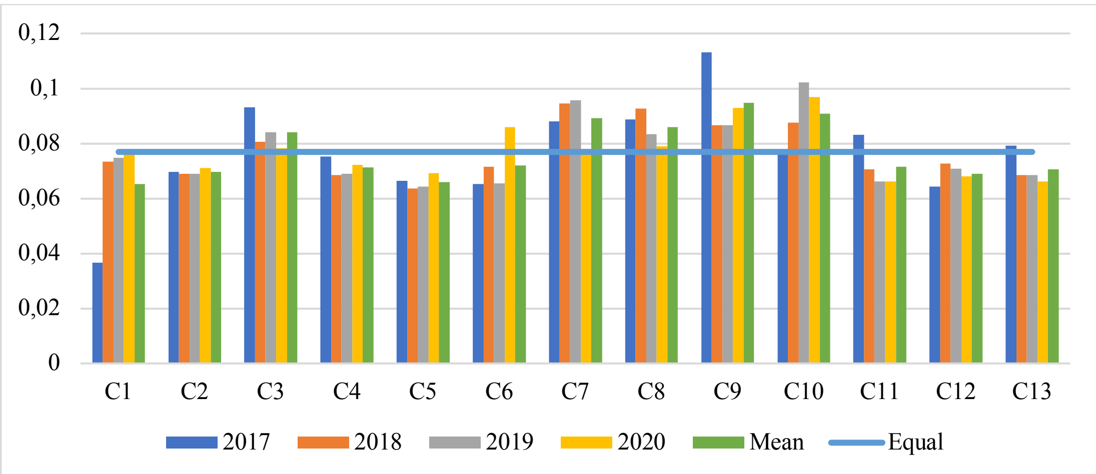
Figure 1. Weights of entropy method



Source: Authors' Calculation

The weight of each criterion obtained by the critic method is represented in Figure 2. As can be seen from Figure 2, the criteria weights are very close to the weights if they are assumed to be equally distributed.

Figure 2. Weights of critic method



Source: Authors' Calculation

Three types of weights (equal, critic, and entropy) are depicted in Figure 3 to provide a more complete picture. With the knowledge of the entropy method applied in numerous scientific papers, even though it is not always appropriate (Paradowski et al., 2021), and the comparison of the three weighting methods, the importance level is

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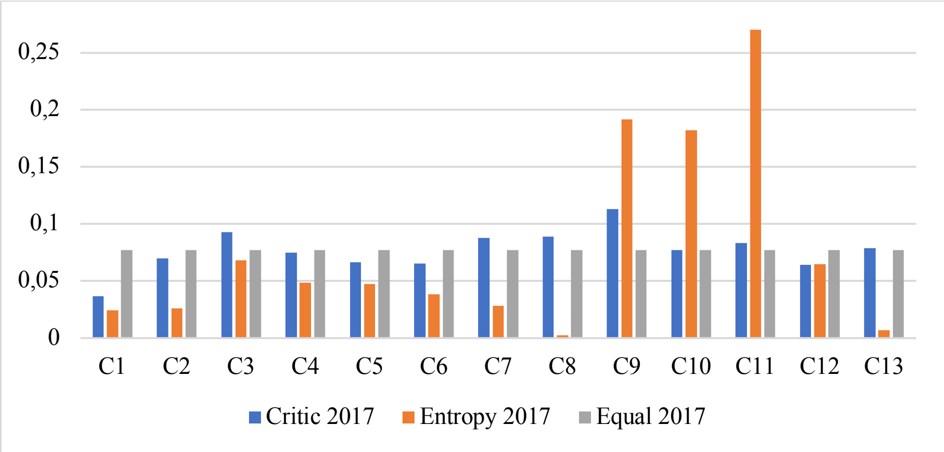
assumed to be equally distributed. The M-EDAS method has been calculated to rank the selected Asian countries and the NSP, NSN, and AS values, are calculated as explained in Section 1.2, as they are shown in Table 2 and Table 3 for the years 2017-2020 in order to see the changes between the years.

Figure 3. Comparison of criteria weights



Source: Authors' calculation

Table 2. Calculation details obtained using M-EDAS method and ranking: 2017 and 2018

M-EDAS	NSP (2017)	NSN (2017)	AS (2017)	Rank (2017)	NSP (2018)	NSN (2018)	AS (2018)	Rank (2018)
China	0.3012	0.6924	0.4968	7	0.3566	0.6495	0.5030	4
Hong Kong	0.8325	0.7154	0.7739	2	0.7217	0.7009	0.7113	3
India	0.1216	0.3745	0.2480	12	0.1437	0.3746	0.2591	12
Indonesia	0.2368	0.6339	0.4354	8	0.0936	0.6012	0.3474	9
Japan	1.0000	0.4561	0.7281	3	1.0000	0.4985	0.7492	2
Kazakhstan	0.4063	0.6531	0.5297	5	0.2471	0.6466	0.4469	7
Malaysia	0.3880	0.8177	0.6028	4	0.3205	0.6411	0.4808	6
Pakistan	*0.0570*	*0.0862*	*0.0716*	*13*	*0.0668*	*0.0836*	*0.0752*	*13*
Philippines	0.5033	0.5132	0.5083	6	0.4483	0.5235	0.4859	5
Singapore	*0.8785*	*0.8577*	*0.8681*	*1*	*0.6955*	*0.8194*	*0.7574*	*1*
Thailand	0.2522	0.5573	0.4047	10	0.2221	0.5404	0.3812	8
Turkey	0.4802	0.3582	0.4192	9	0.3943	0.1782	0.2862	11
Uzbekistan	0.5478	0.0000	0.2739	11	0.6325	0.0000	0.3163	10

Source: Authors' calculation

Singapore is the country with the highest level of development in this selected Asian Group of countries in 2017 and 2018, according to the statistics in Table 2. Pakistan, on the other hand, is the country with the lowest level of development. When we consider 2017 and 2018, Singapore appears to be a benchmark for sustainable development among the 13 Asian countries.

Table 3. Calculation details obtained using M-EDAS method and ranking: 2019 and 2020

M-EDAS	NSP (2019)	NSN (2019)	AS (2019)	Rank (2019)	NSP (2020)	NSN (2020)	AS (2020)	Rank (2020)
China	0.5667	0.6471	0.6069	3	0.0334	0.5445	0.2890	10
Hong Kong	0.7005	0.4607	0.5806	4	0.6329	0.6886	0.6607	2
India	0.1779	0.5427	0.3603	11	0.1559	0.5925	0.3742	7
Indonesia	0.2404	0.6237	0.4320	9	0.0681	0.3991	0.2336	11
Japan	*1.0000*	*0.5911*	*0.7956*	*1*	*1.0000*	*0.6906*	*0.8453*	*1*
Kazakhstan	0.3414	0.6787	0.5101	7	0.1889	0.7229	0.4559	5
Malaysia	0.4107	0.6362	0.5235	6	0.2976	0.6139	0.4558	6
Pakistan	*0.2167*	*0.0626*	*0.1396*	*13*	*0.3311*	*0.0912*	*0.2112*	*12*
Philippines	0.6262	0.5043	0.5653	5	0.3905	0.8285	0.6095	3
Singapore	0.6933	0.5779	0.6356	2	0.6266	0.5313	0.5789	4
Thailand	0.2301	0.5945	0.4123	10	0.2190	0.5168	0.3679	8
Turkey	0.4500	0.0000	0.2250	12	0.4629	0.1227	0.2928	9
Uzbekistan	0.7299	0.1469	0.4384	8	0.3423	0.0000	0.1712	13

Source: Authors' calculation

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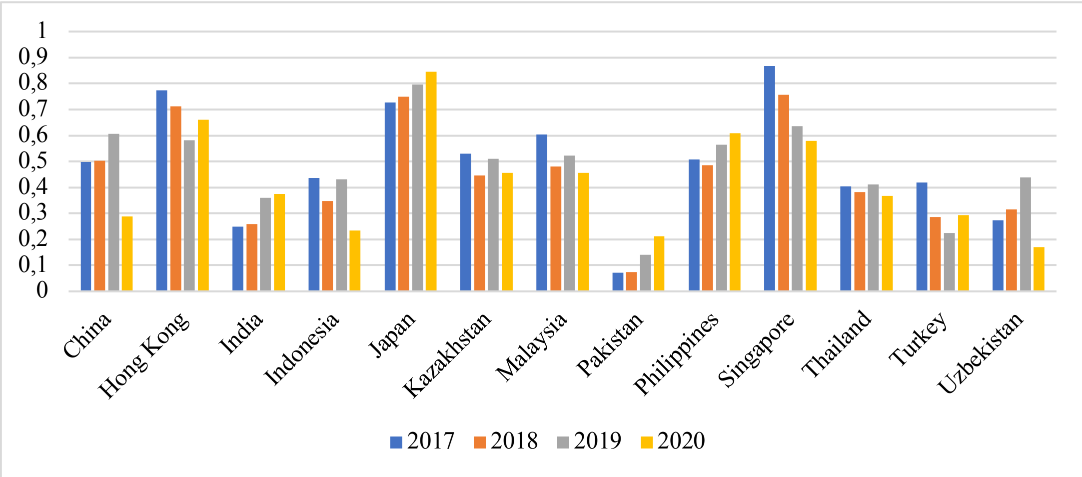
According to the data in Table 3, Japan has the highest level of sustainable development among the selected Asian country groups in 2019 and 2020. Pakistan remained the country with the lowest degree of development in 2019, as in previous years. In contrast, Uzbekistan had the lowest level of development in 2020. Furthermore, six of the 13 countries analyzed in 2020 will achieve less significant sustainable development between 2017 and 2020. These unexpectedly transformed values can be considered evidence of the effects of the COVID-19 pandemic. The results are shown in Figure 4 to illustrate the complete picture more clearly.

Figure 4. AS obtained using EDAS in 2017-2020



The M-EDAS technique ranks the country's overall performance, presuming that a country with greater long-term socio-economic development should be near the top and far from the bottom. Based on this information, countries are classified into four groups based on their ranking: Very High (VH), High (H), Medium(M), and Low(L). When we examine the categorization of the countries, we encounter that only China's categorization group changes from Very High to Low in one-year period (from 2019 to 2020).

Table 4. Groups of selected Asian Countries (VH, H, M, and L)

Country	2017	2018	2019	2020	Explanation
Japan	VH	VH	VH	VH	
Malaysia	H	H	*H*	*H*	Same Category in Four Years
Pakistan	L	L	L	L	
India	L	L	L	M	
Indonesia	M	M	M	L	
Philippines	H	H	H	VH	
Singapore	VH	VH	VH	H	Same Category in Three Years
Hong Kong	VH	VH	H	VH	
Uzbekistan	L	L	M	L	
Kazakhstan	H	M	M	H	
Thailand	L	M	L	M	Same Category in Two Years
Turkey	M	L	L	M	
China	M	H	*VH*	*L*	Different Categories

Source: Authors' calculation

The secondary objective of this study was to predict the effects of the COVID-19 pandemic. To prove this, the ranking analysis results obtained from the M-EDAS method were tested using Spearman's correlation coefficient to compare the periods before and during COVID-19. Table 5 presents the correlation matrix for the study period.

Table 5. Spearman's Correlation between the findings of M-EDAS method

Spearman's Rho	2017 Rank	2018 Rank	2019 Rank	2020 Rank
2017 Rank	1			
2018 Rank	.918	1		
2019 Rank	.852	.962	1	
2020 Rank	.786	.731	.659	1

Source: Authors' calculation

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All correlation coefficients are significant at the level of 0.01 except for the relation between the years 2019 and 2020. In addition, the Spearman correlation coefficients are high and highly significant for all years, but the relationship appears weaker in the last two years than in the previous years, demonstrating the effect of COVID-19.

Because the main aim of this study is to predict the countries' sustainable development level with the fewest general economic indicators, C_7 and C_{12} are chosen to make this prediction with the help of the k-NN algorithm. In addition, 2019 and 2020 are used to test this prediction and explore the effects of COVID-19. The years 2017 and 2018 are the training datasets for predicting 2019. The years 2018 and 2019 are the training datasets for the prediction of 2020. Table 6 illustrates the gained findings of the k-NN algorithm for Hong Kong that belongs to cluster "High" as estimated from the M-EDAS for the year 2019.

Table 6. k-NN Algorithm results for Hong Kong: 2019

2019 Hong Kong		-2,42	2,93	H (M-EDAS Finding)			
Country & Year (Training Dataset)	M-EDAS	C_7	C_{12}	Distance	Sort	Neighbor	Group of Neighbor
2017 China	M	6.30	4.44	1.47	1.32	1	H
2017 Hong Kong	VH	3.02	3.13	1.40	1.37	2	H
2017 India	L	5.67	5.358	1.59	1.39	3	H
2017 Indonesia	M	3.84	3.88	1.49	1.40	4	VH
…	…	…	…	…	…	…	…
2018 Hong Kong	VH	2.03	2.82	1.50	1.56	15	M
2018 India	L	5.43	5.33	1.60	1.59	16	L
2018 Indonesia	M	3.99	4.4	1.56	1.60	17	L

Source: Authors' calculation

The "distance" column computes the distance between all training datasets and the test sample using the Hassanat distance function. The "sort" column ranks the distances from minimum to maximum and the "neighbor" column represents the nearest neighbor. As shown in Table 6, if the value of k is equal to 1, the prediction for Hong Kong is "High". In addition, the finding of the M-EDAS method for Hong Kong in 2019 is also High. Table 7 represents the k-NN algorithm findings for different values of k for all selected Asian countries in 2019.

Table 7. k-NN Findings for selected Asian Countries: 2019

	VH	*H*	L	M	*VH*	M	H	L	L	L	M
k	China	*Hong Kong, Philippines*	India	Indonesia	*Japan, Singapore*	Kazakhstan	Malaysia	Pakistan	Thailand	Turkey	Uzbekistan
1	M	*H*	M	M	*VH*	M	VH	VH	M	L	L
2	ND	*H*	ND	ND	*VH*	ND	ND	ND	ND	ND	L
3	ND	*H*	ND	ND	*VH*	ND	VH	H	ND	L	L
4	L	*H*	L	M	*VH*	M	VH	H	VH	L	L
5	L	*H*	L	ND	*VH*	ND	ND	H	VH	L	L
6	ND	*H*	L	ND	*VH*	ND	ND	ND	VH	L	L
7	L	*H*	L	ND	*VH*	L	ND	ND	VH	L	L
8	ND	*H*	L	ND	*VH*	L	ND	VH	VH	L	L
9	ND	*H*	L	VH	*VH*	L	VH	VH	VH	L	L

Source: Authors' calculation

Table 7 shows that the prediction is accurate for all k values for Hong Kong, the Philippines, Japan, and Singapore. Turkey's prediction is inaccurate only when k is equal to 2. However, for China, Malaysia, Pakistan, Thailand, and Uzbekistan, the algorithm cannot predict the belonging group for any value of k. When the k values are greater than 3, the algorithm makes an accurate prediction for India. When k is equal to one or four, the algorithm accurately predicts Indonesia and Kazakhstan. Because the value of k degrades the algorithm's performance, identifying the most accurate prediction number is vital. As shown in Table 7, when k is equal to 4, 8 countries' (Hong Kong, the Philippines, Japan, Singapore, India, Indonesia, Kazakhstan, and Turkey) prediction is accurate among the 13 selected Asian countries. Because a majority vote makes classification decisions in the basic k-NN algorithm, the algorithm cannot decide (ND) for China when k equals 2. In addition, the same issue occurs when k is equal to 3 and 6 for China. Table 8 summarizes the results of the k-NN algorithm for all k values for all selected Asian countries in 2020.

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Table 8. k-NN Findings for selected Asian Countries: 2020

	L	VH	M	L	VH	H	H	L	VH	H	M	M	L
k	China	Hong Kong	India	Indonesia	Japan	Kazakhstan	Malaysia	Pakistan	Philippines	Singapore	Thailand	Turkey	Uzbekistan
1	L	H	H	H	H	H	H	H	H	H	H	L	L
2	L	ND	ND	H	H	ND	ND	H	H	H	ND	L	ND
3	L	L	ND	H	H	ND	H	H	H	H	H	L	L
4	*L*	L	*M*	H	H	*H*	*H*	H	H	*H*	H	ND	*L*
5	L	ND	ND	ND	H	H	H	ND	H	ND	H	ND	L
6	L	ND	ND	ND	H	ND	ND	ND	H	ND	H	M	L
7	L	ND	ND	ND	H	ND	ND	ND	H	ND	H	ND	L
8	ND	L	H	ND	H	ND	ND	ND	H	ND	H	ND	L
9	ND	L	H	L	H	M	H	L	H	L	H	L	L

Source: Authors' calculation

Table 8 shows that the prediction is accurate when k is equal to 4 for six countries (China, India, Kazakhstan, Malaysia, Singapore, and Uzbekistan). However, for Hong Kong, Japan, the Philippines, and Thailand, the algorithm cannot predict the belonging group for any value of k.

5. Conclusion and discussion

This study aims to forecast the sustainable development level of any country with the fewest possible parameters based on social, economic, and environmental dimensions. For this purpose, a hybrid model consisting of multi-criteria decision-making and a machine learning method is proposed. Asian countries have been used as an example to demonstrate the applicability of the hybrid model since the impact of the COVID-19 pandemic on these countries is well-documented. However, one important limitation of this study is the limited availability of data on Asian countries.

To predict the sustainable development level of any country using machine learning, we must know the country's sustainable development level for at least one year to train the algorithm and make predictions based on experience. Therefore, in the first part of the study, the M-EDAS method was used to determine the sustainable development level of any country. Additionally, the selected Asian countries were ranked based on indicators related to the goals of the Sustainable Development Report, with the help of the M-EDAS method. However, some of the main indicators mentioned in this report could not be selected due to a lack of data. On the other hand, the indicators used in the study were selected based on their importance and effectiveness on the main indicators. The selection of indicators is crucial because it affects the findings of the ranking analysis. Through these ranking analyses, countries were categorized, and their sustainable development levels were determined.

The findings obtained by the M-EDAS method revealed that the most developed country is Singapore for the years 2017 and 2018, Japan for the years 2019 and 2020; and the least developed country is Pakistan except in 2020. In 2020, Uzbekistan was the least developed country based on the 13 indicators. Moreover, the results highlighted those countries identified as having the lowest sustainable development rank had the lowest property rights value in specific years.

To assess the impact of the COVID-19 pandemic, the relationship between years of ranking was calculated using Spearman's correlation. The findings highlight that the relationship appeared weaker in the last two years than in previous years. For the second part of the application, 2019 and 2020 were used to test the prediction, and the last two years before the relevant year were used as the training dataset. GDP and unemployment rate variables were used to predict the sustainable development level with the help of the k-NN algorithm. In other words, to predict the year 2019, we train the algorithm with the findings of the year 2018 and 2017 from the M-EDAS method. According to the findings of the hybrid model proposed for 2019, the forecasts of eight countries were correct for k=4, and the forecasts of the four countries were correct for all k values. However, the 2020 forecast was not as successful as that of 2019.

Finally, the proposed hybrid model for prediction is tested for the years 2019 and 2020. To make an appropriate prediction, each country has a 1/4 probability. Out of the 13 selected Asian countries, 8 of them have accurate predictions for k=4. Additionally, 4 of them have accurate predictions for all values of k. However, the prediction

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for 2020 was not as accurate as that for 2019. One reason for this could be attributed to the impact of COVID-19. The findings indicate that combining multi-criteria decision-making and machine learning methods can be used for forecasting, regardless of the variables. Furthermore, it is critical to remember that this study has significant limitations. First, not all Asian countries were investigated because of the lack of statistical data. Second, because not all the necessary statistics and values of the indicators were announced for 2021 and 2022, the proposed model cannot be applied for these years, and its accuracy of the proposed model cannot be determined continuously.

The findings of this study suggest that the combination of multi-criteria decision-making and machine learning methods can be effectively employed in forecasting, irrespective of time, country, and variables. This approach offers potential for future research to estimate the levels of different country groups across various fields while utilizing a reduced set of parameters.

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Author contribution statements

The authors contributed equally to the research's design and implementation, analysis, and the manuscript's writing.

Disclosure statement

The authors reported no potential conflict of interest.

Ethics committee approval

Some part of this study was previously published as Congress abstract paper (Oriental Business and Innovation Center Conference, 5-6 May 2022, Budapest). All responsibility belongs to the researchers. All parties were involved in the research of their own free will. Ethics committee approval is not required as this study did not collect data on humans using experiments, methods, practices, etc.

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