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FUZZY ESTIMATION OF ECOLOGICAL PERFORMANCE INDEX (EPI)

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Abstract. The Environmental Performance Index (EPI) is a method of quantifying and numerically marking the environmental performance of a state's policies. Present paper studies questions of EPI calculation for country's group with the purpose to range the state of ecologic system using intuitionistic fuzzy modeling method.

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1 Introduction

The purpose of this paper is to study the issue of ranking group of countries, which have close economic, geographic and historical ties with our country, on sustainable development. The concept of sustainable development of the countries is known to be associated with ESI (Environmental sustainability index) and EPI (Environmental performance index) notions, which have been calculated by Yale and Columbia universities in the USA for the most countries in the world since 2006.

Environmental Performance Index (EPI) - is a method of quantifying and benchmarking the environmental policy of the world states. EPI ranks countries on performance in several categories, which are combined into two groups: the viability of ecosystems and ecological health.

EPI for countries includes the measurement of development impacts in two ways: by population health and viability of ecosystems through the behavior of 9 major factors in 2016 (10 factors in 2012-2014 years). Initial data for the group of countries over the year of 2016 are given in Table 1[6].

Country	2016 EPI Score	EH	EV	HI	AQ	WS	WR	AG	FOR	FISH	BAH	CAE
Azerbaijan	83,78	82,96	84,6	89,77	80,99	78,12	69,16	98,18	96,7	69.80	75,83	97,94
Russia	83,52	87,06	79,98	92,2	84,76	84,22	91,28	98,18	49,17	57,81	73,7	84,42
Turkey	67.68	79.6	55.76	74,43	79,3	85,06	78,99	87,04	68,48	57,82	22,53	47,77
Iran	66,32	72,26	60,38	63,21	76,68	76,89	55,91	92,39	62.8	33,17	64,16	53,88
Georgia	64.96	78.12	51.81	75,1	79,96	79,31	0	98,18	100	31,85	70,31	51,28

Table 1 Factors values of EPI by Yale University

EH - Environmental Health

HI - Health Impacts;

AQ - Air Quality;

WS - Water and Sanitation;

EV - Environmental Vitality

WR - Water Resources;

AG - Agriculture;

FOR - Forests;

FISH - Fisheries;

BAH - Biodiversity and Habitat;

CAE - Climate and Energy.

In the new approach, ranking values of EPI are used for calculating the correlation coefficient of fuzzy decision-making, weight coefficient of correlation calculated on the basis of intuitionistic fuzzy sets (IFS). IFS - contains two kinds of sides by means of the membership and non-membership concepts. By construction, the IFS have the following assumptions:

Definition 1. An IFS A in X in given by

$$A = \{\langle x, \mu_A(x), \upsilon_A(x)\rangle | x \in X\} \tag{1}$$

where $\mu_A(x) : X \to [0,1]$ and $\upsilon_A(x) : X \to [0,1]$, with the condition $0 \leq \mu_A(x) + \upsilon_A(x) \leq 1$. The numbers $\mu_A(x)$ and $\upsilon_A(x)$ represent, respectively, the membership degree and nonmembership degree of the element x to the set A [1].

The value of π is "intuitive index", which represents the degree of indecision, the fluctuation degree of inclusion of x variable to A set. Description of the numerical values of indicators calculated on a 100-point scale is normalized, then transferred to the intuitive fuzzy numbers as follows. The actual data are grouped into five linguistic subsets (VL, L, M, H, VH). The logic is that if the actual value of the factor is included in VH in the interval (0.8 - 1.0), the most likely entry hesitancy of the studied state belongs to the interval (0 - 0.2). Moreover, values close to 0.8, corresponds the value of indecision $\pi(x) = 0.2$. If the actual value of the factor is very close to 1, the value of intuitive index will be $\pi(x) = 0$ (the compliance has a inversely symmetrical character). It is obvious that in such a transformation the middles of the intervals become the exact middles (means) of intervals according to the values of indecision $\pi(x)$. This can be described graphically as follows:

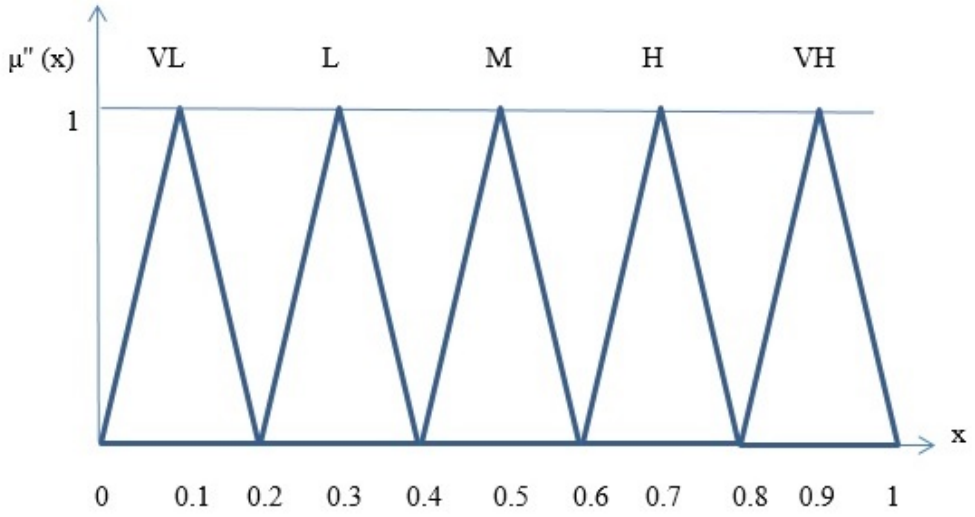

Figure 1. Normalized values of real datas

π - decreasing step function of $\mu^{''}(x)$, where $\mu^{''}(x)$ is the value of real-normalized data for each factor of EPI.

The procedure of constructing IFS is demonstrated in HI (Health Impact) Index for Azerbaijan, which is equal to normalized value 0.8977 in the year of 2016. Intuitive index corresponding to this value is equal to $\pi(x) = 0.1$. Then the values of membership and non-membership functions respectively equal to:

$$\mu(HI_{AZ}) = 0.8977 * (1 - 0.1) = 0.81,\ \upsilon(HI_{AZ}) = 1 - 0.81 - 0.1 = 0.09.$$

Thus, IFS for the value of HI in 2016 is described as triplet (0.81, 0.09, 0.1). Table 2 shows the calculated values of IFS over all factors of EPI in five countries.

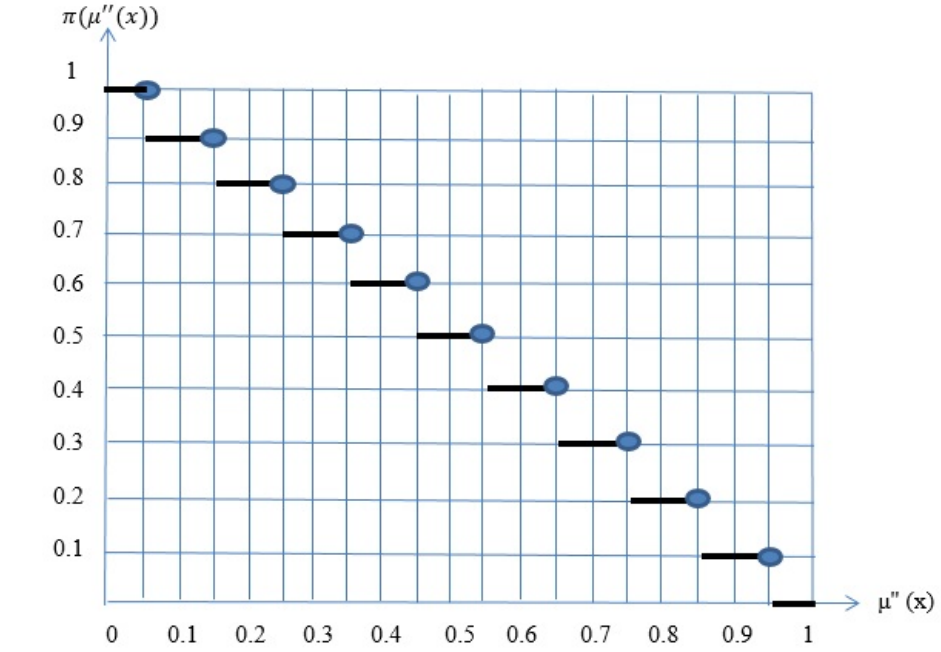

Figure 2. Values of indecision π.

Country	HI			AQ			WS			WR			AG		
Azerbaijan	0,81	0,09	0,1	0,65	0,15	0,2	0,62	0,18	0,2	0,48	0,22	0,3	0,98	0,02	0
Russia	0,82	0,07	0,1	0,68	0,12	0,2	0,67	0,13	0,2	0,82	0,08	0,1	0,98	0,02	0
Turkey	0,52	0,18	0,3	0,63	0,17	0,2	0,77	0,14	0,1	0,63	0,17	0,2	0,78	0,12	0,1
Iran	0,38	0,22	0,4	0,61	0,19	0,2	0,62	0,18	0,2	0,34	0,26	0,4	0,83	0,07	0,1
Georgia	0,53	0,17	0,3	0,64	0,16	0,2	0,64	0,16	0,2	0	0	1	0,98	0,02	0

Continued Table 2

Country	FOR			FISH			BAH			CAE		
Azerbaijan	0,97	0,03	0	0,43	0,21	0,3	0,61	0,19	0,2	0,979	0,02	0,001
Russia	0,25	0,25	0,5	0,35	0,25	0,4	0,52	0,18	0,3	0,68	0,12	0,2
Turkey	0,48	0,22	0,3	0,35	0,25	0,4	0,05	0,16	0,8	0,29	0,21	0,5
Iran	0,38	0,22	0,4	0,1	0,2	0,7	0,39	0,21	0,4	0,27	0,23	0,5
Georgia	0,1	0	0	0,1	0,2	0,7	0,49	0,21	0,3	0,26	0,24	0,5

Table 2 Calculated values of IFS over all factors of EPI

According to the method presented in [2] we directly calculate the EPI values for the above mentioned countries taking into account the definition of the relevant concepts, which are necessary to calculate the fuzzy correlation coefficient between the two IFS introduced in [5], [4], [7] and [2].

Definition 2. The correlation coefficient between the IFS, as defined in $X = \{x_1, x_2, ..., x_n\}$ [5]

$$k(A, B) = \frac{C(A,B)}{\sqrt{T(A)*T(B)}}, \tag{2}$$

where

$$C(A,B)=\sum_{i=1}^{n}(\mu_A(x_i)*\mu_B(x_i)-\upsilon_A(x_i)*\upsilon_B(x_i)), \tag{3}$$

$$T(A)=\sum_{i=1}^{n}(\mu_A^2(x_i)+\upsilon_A^2(x_i)). \tag{4}$$

$T(A)$, $T(B)$ - the so-called information and intuitive energy of A and B sets respectively.

Definition 3. Definition of intuitive entropy of IFS is given in [4]:

$$H(A)=\sum_{i=1}^{5}(1-\mu_A(x_i)-\upsilon_A(x_i))=\sum_{i=1}^{5}\pi_A(x_i). \tag{5}$$

Definition 4. Weight coefficient of correlation is calculated as follows [7]:

$$W_i(A^*,A_i)=\frac{\sum_j^n(\mu_A(c_j))}{\sqrt{\sum_{j=1}^n w_j*(\mu_{A_i}^2(c_j)+\upsilon_{A_i}^2(c_j))}}. \tag{6}$$

In case of the information about the weight criterion C_j being generally unknown, the entropy weights model for defining the weight criterion is used by means of the formula (7):

$$W_i=\frac{1-H_i}{n-\sum_{j=1}^n(H_j)}. \tag{7}$$

Step 1. According to the formula (5) we calculate the entropy of each criterion and place in table 3. For example,

$$H_1=\frac{\sum_1^5(H_{1i})}{5}=\frac{0.1+0.1+0.3+0.4+0.3}{5}=0.225,$$

$$H_2=\frac{\sum_1^5(H_{2i})}{5}=\frac{0.2+0.2+...+0.2}{5}=0.2.$$

Therefore, fill in Table 3.

H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	$\sum_1^9(H_i)$	$9-\sum_1^9(H_i)$
0.225	0.2	0.175	0.25	0.05	0.35	0.55	0.425	0.3	2.66	6.34

Table 3 Values of the entropy criteria

Step 2. Using the formula (7) the weight of entropy criteria is calculated and placed in Table 4.

w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9
0.1199	0.1262	0.129	0.095	0.1514	0.1136	0.066	0.0946	0.1041

Table 4 Obtained values of the weights of entropy criteria

Step 3. Next, on the basis of IFS values (Table 2) and calculated weights of the criteria according the formula (7) the correlation coefficients for five countries, which will eventually give a ranking of country groups with EPI index are computed. According to our calculations, EPI ranking values have been converged with results calculated for these countries by Yale and Columbia universities in the USA [6].

According to our calculations, the following values for EPI 2016 have been obtained:

Rank	Countries	EPI 2016	EPI 2016 (Yale)	EPI weight in group	Change direction of EPI values with regard to Yale values
1	Azerbaijan	95.43	83.78	0.2139	0.229
2	Russia	92.71	83.52	0.2079	0.228
3	Turkey	88.07	67.68	0.1975	0.185
4	Iran	85.29	66.32	0.1912	0.181
5	Georgia	84.46	64.96	0.1894	0.177

Table 5 Obtained results for EPI 2016

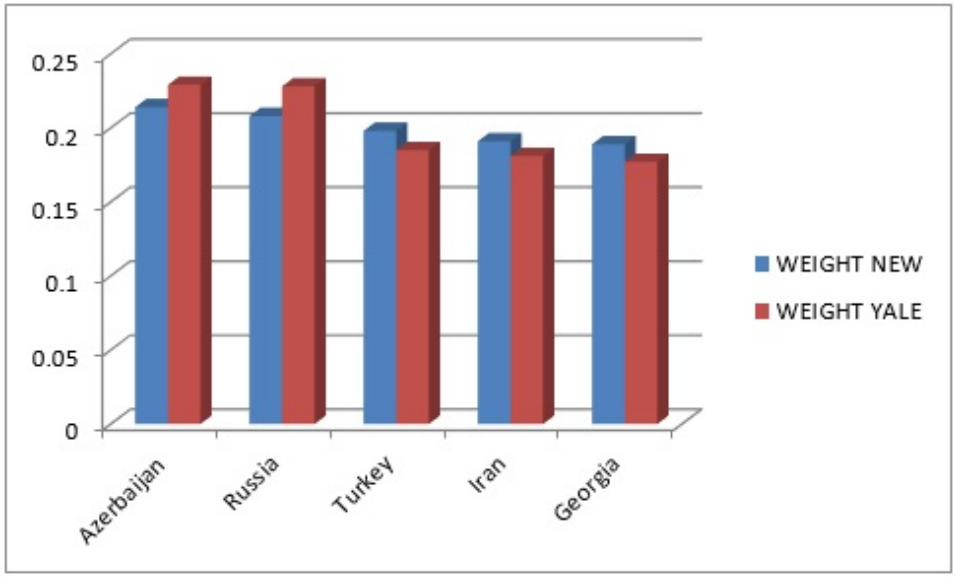

Figure 3. Comparison values of Yale and proposed calculations.

EPI calculation of Yale method is a simplified calculation of mean arithmetic values, which is not adequate enough in case of data with extreme estimates. The use of intuitive fuzzy entropy weights makes possible to achieve computing the value of the ecological state of countries in more sophisticated mathematical way. As seen from the table 5 there is no difference in EPI sequence of priority values of the countries, however specific weights have changed. As a result, we can state that regarding to our estimations calculation of EPI shares by Yale University is overstated for values of Azerbaijan and Russia, and understated for the rest of the countries, which is clearly seen from the above given Figure 3.

2 Conclusion

Applying the proposed method, we came to the conclusion that in our case the ranks of the ecological state index by countries did not change, however the accuracy of calculations increased through the identifying dynamics in the vicinity of the values of these indices.

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