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CALCULATION ECOLOGICAL SECURITY INDEX USING APPARATE OF INTUITIONISTIC FUZZY SETS

Murtuzaeva M.M.[1], Pur Riza S.M.[2] (Republic of Azerbaijan)
Email: Murtuzaeva515@scientifictext.ru

[1]Murtuzaeva Malahat Mustafaevna - PhD in Economics, Science Worker;
[2]Pur Riza Samir Masudovich - PhD in Economics, Science Worker,
FUZZY ECONOMY LABORATORY,
CONTROL SYSTEM INSTITUTE OF NATIONAL ACADEMY OF SCIENCES OF AZERBAIJAN,
BAKU, REPUBLIC OF AZERBAIJAN

Abstract: *the ecological factor is one of the most important indicators of sustainable development. Ecological security is protection status from potential impacts on environment. In this article the ecological security index was calculated, as well as its current state using the example of one of the countries for the period of 2010-2016-th years by harnessing the apparatus of intuitionistic fuzzy sets (IFS), which was proposed by K. Attanasov [1] and attracted the attention of researches by applying it in the different fields.*
Keywords: *ecological security, aggregate index, entropy, PSR models, intuitionistic index, intuitionistic fuzzy sets.*

ВЫЧИСЛЕНИЕ ИНДЕКСА ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ С ПРИМЕНЕНИЕМ АППАРАТА ИНТУИЦИОНИСТСКИХ НЕЧЕТКИХ МНОЖЕСТВ

Муртузаева М.М.[1], Пур Риза С.М.[2] (Азербайджанская Республика)

[1]Муртузаева Малахат Мустафаевна – кандидат экономических наук, научный сотрудник;
[2]Пур Риза Самир Масудович – кандидат экономических наук, научный сотрудник,
лаборатория нечеткой экономики,
Институт систем управления
Национальной академии наук Азербайджана,
г. Баку, Азербайджанская Республика

Аннотация: *экологический фактор является одним из самых важных показателей устойчивого развития. Экологическая безопасность – это состояние защищенности от всевозможных влияний на окружающую среду. В данной статье вычислено значение индекса экологической безопасности, а также его состояния в период за 2010 - 2016-е годы на примере одной из стран использованием аппарата интуиционистских нечетких множеств (IFS), который был предложен К. Аттанасовым [1],*

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и привлекшим внимание исследователей применением его в различных областях.

Ключевые слова: *экологическая безопасность, агрегированный индекс, энтропия, модель PSR, интуиционистский индекс, интуиционистские нечеткие множества.*

Ecologic security - permissible level of negative impacts of natural and man-made factors on the environment and humans.

The ecological security index is calculated on the base of 22 indicators, which are included in 10 categories. The highest value of the Ecological security Index among the countries of the world falls on Finland (90.68), Iceland (90.51) [1]. Integral assessment ecological security is actual for estimation national security of every state

When using, transporting oil, all components of the natural environment (atmospheric air, surface and underground waters, topography, land and vegetation cover, wildlife) exposed to significant transformation This circumstance significantly increases the relevance of such a problem as the calculation of the aggregate Ecological security index of such a region as Azerbaijan, where the oil industry is still one of the main sectors of the economy When modeling in view of statistical possibility of available data as set of criteria authors have chosen 17 factors that have the most influence on integral estimation of index of ecological security in the region, with further linear normalization of all indicators taking into account their negative and positive effects on environment.

$$y_{ij} = \frac{x_{max} - x_{ij}}{x_{max} - x_{min}} \quad \text{- positive}$$

$$y_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \quad \text{- negative} \qquad (1)$$

It would be better to normalize in the entire permissible set according to the world values of each factor (let's assume the normalization of the factor "population density" in the interval from the value of this indicator in Japan, where it is the highest, to the value of the country where this indicator is the lowest). But the selected set, consisting of 17 criteria, does not allow taking into account the general population for all these criteria.

Therefore, we had to be content with a selection of statistical data for the 2010-2016-th years. plunging into a fuzzy environment, expanding the interval of criteria selection in the following tables (Table 1.2) [2] We will designate these criteria in abbreviated English translation: Population density per km2-PDI; Population Growth Rate - PGR; Oil and natural gas production (thousand AZN) - MOG; Cost of construction work - CCW; Number of cars - NA; The number of cattle (1000) - NC; Carbon dioxide (CO2) (thousand tons) - CD; Nitric oxide (N2O) (thousand tons) - NO, Methane (CH4) (thousand tons) - QM; Emissions of pollutants into the atmosphere from automobiles (thousand tons) - APEA; Erosion of the entire land area (ha) - EES; Pollutants released into the

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atmosphere (thousand tons) - APE; Polluted water emissions through wastewater (mln m3) - WWP; Reserves (km2) - RS; Investments aimed at protecting the environment (thousand AZN) - EPI; Science expenses (thousand AZN) - SE; The share of energy supply from renewable energy sources of the total energy supply, % - ESS.

Table 1. PSR Model Indicators of Azerbaijan

		Indicators	**2010**	**2011**	**2012**	**2013**	**2014**
P	1	PDI	105	107	108	109	111
	2	PGR	12.5	13.5	13.0	12.8	12.2
	3	MOG	20198.7	26055.4	24747.0	23658.0	20977.0
	4	CCW	4531384.	6115011.	7716020.	8721165.	8591861.
	5	NA	982553.0	1037626.	1135936.	1232678.	1291008.
	6	NC	2582.4	2613.7	2647.9	2678.2	2703.3
S	7	CD	14399.6	13809.4	12471.4	15135.8	16091.9
	8	NO	11.8	25.9	15.8	5.0	4.7
	9	QM	18.3	298.3	385.2	248.8	95.7
	10	APEA	742	779	849	940	966
	11	EES	3743.5	3733.05	3722.53	3712.23	3701.87
	12	APE	214.8	224.0	226.5	197.3	189.3
	13	WWP	6005.0	5068.0	5365.0	5154.0	5347.0
R	14	RS	8807.74	8807.74	8925.5	8925.5	8925.5
	15	EPI	260673.8	320253.5	419317.9	398187.5	283414.6
	16	SE	92.8	106.1	116.7	117	124.2
	17	ESS	3.1	2.4	1.8	2.0	1.8

Continues Table 1

		Indicators	**2015**	**2016**
P	1	PDI	111	112
	2	PGR	11.7	10.6
	3	MOG	14723.0	18853.0
	4	CCW	7319551.9	7660351.2
	5	NA	1322610.0	1347812
	6	NC	2697.5	2708.3
S	7	CD	13980.8	14911.2
	8	NO	7.0	3.3
	9	QM	34.1	41.0
	10	APEA	978	982
	11	EES	3691.53	5196
	12	APE	178.0	187.6
	13	WWP	5573.0	5670.0
R	14	RS	8925.5	8925.5
	15	EPI	136208.3	155817.2
	16	SE	113.2	110.2
	17	ESS	1.9	1.8

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Based on this table, we will build a new extended table of criteria with subsequent normalization, according to the above formulas (table 2). The first 13 factors are accepted as negative factors.

Table 2. Criteria with subsequent normalization

	Statistic	**New interval**	**New Interval Length**	**Normalized value μ''(2010)**
1	105-112	104,6-112,35	7,75	0,051613
2	10.6-13.5	10,46-13,65	3,19	0,639498
3	14723-26055.4	14156,4-26622	12465,6	0,484718
4	4531385-8721165	4321896-8930654	4608758	0,045455
5	982553-1347812	617294-1713071	1095777	0,333333
6	2582.4-2708.3	2576,1-2714,6	138,5	0,045487
7	12471.4-16092	12290,4-16273	3983	0,529551
8	3.3-25.9	2,17-27,03	24,86	0,387369
9	18.3-385.2	0-403,5	403,5	0,045353
10	742-982	730-994	264	0,045455
11	3691-5196	3616,3-5271,2	1654,9	0,076863
12	178-226.5	175,6-228,9	53,3	0,73546
13	5068-6005	5021-6052	1031	0,954413
14	8801-8925.5	8801,8-8931,4	129,6	0,954167
15	136208.3-419318	131053,3-424473	293419,7	0,558242
16	92.8-131.7	91,23-125,77	34,54	0,954545
17	1.8-3.1	1,74-3,165	1,425	0,045614

ESI values are calculated using the PSR (pressure-state-response) model, the structure of which was proposed by Anthony Friend and David Rapport, using the theory of intuitive fuzzy sets [6], [1]. This instrument allows one to more accurately take into account the situation (to take into account the situation more accurately, since in this case it is possible not only to state the value of the non-occurrence of the variable in a particular set, but also the degree of confidence of such a statement, and the sum of the values of the degree of belonging and not belonging is not always one. Numbers are described not on a plane, but due to the appearance of a degree of uncertainty (π), the description is translated into three-dimensional space. And so a fuzzy intuitive number, is taken as a triad of numbers, where starting with a real normalized statistical indicator, the first duty is to establish the “indecision index”, “intuitiveness index”. If the normalized value is high (close to one), in an permissible range of values, then the intuitionistic index is equal to zero. All values are graded according to the table 3[3].

Table 3. Calculation of the intuitionistic index π (x) depending on the normalized value data

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Convert to $\pi(x)$	$\mu''(x)$	$\pi(x)$
VL	0.0-0.2	0.8-1.0
L	0.2-0.4	0.6-0.8
M	0.4-0.6	0.4-0.6
H	0.6-0.8	0.2-0.4
VH	0.8-1.0	0.0-0.2

where VL is a very low value of μ"(x); L is a low value of μ"(x); M is the average value of μ"(x); H is the high value of μ"(x); VH is a very high value of μ"(x).

μ"(x) is the normalized value of the statistical indicator;

π (x) is the intuitiveness index(intuitionistic index) corresponding to the value μ"(x)

Next, the values of membership are calculated according to the following formula [1]:

$$\mu(x) = \mu''(x) * [1 - \pi(x)] \qquad (2)$$

The third component of the intuitionistic fuzzy number ν(x), which means the value of the degree of non-membership of the set, is calculated by means of equality

$$\nu(x) = 1 - \mu(x) - \pi(x) \qquad (3)$$

After calculating the intuitionistic fuzzy numbers for all factors for the researched period (Table 4), we move on to the definition of the aggregated ecological security index (AESİ) by years, as the sum of entropy multiplied by the corresponding weights of the selected seventeen indicators. Since fuzzy entropy IFS is (4), and the aggregated index of ecological security is (AESİ) (5), [1], [4], [5].

$$E = \frac{\pi + \min(\mu,\nu)}{\pi + \max(\mu,\nu)} \qquad (4)$$

$$AESI = \sum_{i=1}^{17} \mu''(x_i) * w(x_i) \qquad (5)$$

Let's demonstrate what we've said in detail for 2010. Since the factor (population density) has a negative effect, the normalized value of this factor is 0.056

$\mu''_{2010}(x_1) = \frac{105-104.6}{7.750} = 0.052$

According to table 3, we take the corresponding value of π as 1. According to the formula (2)

$\mu_{2010}(1) = 0.052 * (1 - 1) = 0$

In this case, the third component of IFS is:

$\nu_{2010}(1) = 1 - 1 - 0 = 0$

IFS= (0,0,1) – there is an intuitionistic number that meets the first criterion in 2010.

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The total IFS values for all factors of the researched period are placed in table 4

Table 4. Total IFS values for all factors of the researched period

	2010	2011	2012	2013
1	(0,0,1)	(0.093,0.207,0.7)	(0.197,0.253,0.55)	(0.341,0.259,0.4)
2	(0.42,0.23,0.35)	(0.905,0.045,0.05)	(0.637,0.163,0.2)	(0.513,0.187,0.3)
3	(0.24,0.26,0.5)	(0.907,0.043,0.05)	(0.722,0.128,0.15)	(0.572,0.178,0.25)
4	(0,0,1)	(0.156,0.244,0.6)	(0.552,0.198,0.25)	(0.907,0.043,0.05)
5	(0.1,0.2,0.7)	(0.153,0.247,0.6)	(0.237,0.263,0.5)	(0.337,0.263,0.4)
6	(0,0,1)	(0.081,0.219,0.7)	(0.259,0.241,0.5)	(0.553,0.197,0.25)
7	(0.26,0.24,0.5)	(0.153,0.247,0.6)	(0.002,0.048,0.95)	(0.5,0.2,0.3)
8	(0.15,0.25,0.6)	(0.907,0.043,0.05)	(0.302,0.248,0.45)	(0.01,0.09,0.9)
9	(0,0,1)	(0.554,0.196,0.25)	(0.907,0.043,0.05)	(0.37,0.23,0.4)
10	(0,0,1)	(0.037,0.163,0.8)	(0.203,0.247,0.55)	(0.636,0.164,0.2)
11	(0,0.1,0.9)	(0.007,0.093,0.9)	(0.004,0.056,0.94)	(0.003,0.047,0.95)
12	(0.51,0.19,0.3)	(0.817,0.083,0.1)	(0.907,0.043,0.05)	(0.163,0.237,0.6)
13	(0.95,0.05,0)	(0.002,0.048,0.95)	(0.117,0.233,0.65)	(0.019,0.131,0.85)
14	(0.95,0.05,0)	(0.906,0.044,0.05)	(0.002,0.048,0.95)	(0.002,0.048,0.95)
15	(0.33,0.27,0.4)	(0,124,0,226,0.65)	(0,0.02,0.98)	(0.009,0.091,0.9)
16	(0.95,0.05,0)	(0.342,0.258,0.4)	(0.066,0.184,0.75)	(0.063,0.187,0.75)
17	(0,0,1)	(0.295,0.255,0.45)	(0.91,0.04,0.05)	(0.654,0.146,0.2)

Continues Table 4

	2014	**2015**	**2016**
1	(0.661,0.139,0.2)	(0.661,0.139,0.2)	(0.936,0.044,0.02)
2	(0.3,0.25,0.45)	(0.156,0.244,0.6)	(0.002,0.048,0.95)
3	(0.301,0.249,0.45)	(0.002,0.048,0.95)	(0.151,0.249,0.6)
4	(0.834,0.066,0.1)	(0.423,0.227,0.35)	(0.507,0.193,0.3)
5	(0.369,0.231,0.4)	(0.386,0.214,0.4)	(0.433,0.217,0.35)
6	(0.827,0.073,0.1)	(0.789,0.111,0.1)	(0.907,0.043,0,05)
7	(0.907,0.043,0.05)	(0.17,0.23,0.6)	(0.428,0.222,0.35)
8	(0.01,0.089,0.9)	(0.039,0.161,0.8)	(0.002,0.048,0.95)
9	(0.057,0.183,0.76)	(0.008,0.092,0.9)	(0.01,0.089,0.90)
10	(0.805,0.095,0.1)	(0.883,0.057,0.06)	(0.907,0.043,0.05)
11	(0.003,0.047,0.95)	(0.002,0.048,0.95)	(0.907,0.043,0.05)
12	(0.064,0.186,0.75)	(0.002,0.048,0.95)	(0.045,0.155,0.8)
13	(0.095,0.205,0.7)	(0.289,0.251,0.46)	(0.378,0.222,0.4)
14	(0.002,0.048,0.95)	(0.002,0.048,0.95)	(0.018,0.382,0.6)

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15	(0.24,0.26,0.5)	(0.963,0.017,.0.02)	(0.824,0.076,0.1)
16	(0.002,0.048,0.95)	(0.135,0.235,0.63)	(0.203,0.247,0.55)
17	(0.91,0.04,0.05)	(0.799,0.101,0.1)	(0.91,0.04,0.05)

We continue the calculation using the example of 2010. Since the value of IFS in 2010 (is (0,0,1),) according to the indicator "Population density", then the entropy is

$$E_{2010}(x_1) = \frac{\pi + \min(\mu, \nu)}{\pi + \max(\mu, \nu)} = \frac{1+0}{1+0} = 1.0$$

Calculating the value of entropy for other factors in 2010, we will find the specific weights of factors the following way:

$$w_i(t) = \frac{E_i(t)}{\sum_{i=1}^{17} E_i(t)}$$

Fill in the values E_i and w_i in table 5

Table 5. Entropy and weight values for all factors

N	2010		2011		2012		2013	
	E_i	w_i	E_i	w_i	E_i	w_i	E_i	w_i
1	1	0,077	0,874	0,080	0,931	0,078	0,890	0,073
2	0,758	0,058	0,099	0,009	0,434	0,036	0,598	0,049
3	0,977	0,075	0,097	0,009	0,319	0,027	0,521	0,042
4	1	0,077	0,895	0,081	0,558	0,047	0,097	0,008
5	0,889	0,068	0,890	0,081	0,965	0,081	0,900	0,073
6	1	0,077	0,851	0,077	0,976	0,082	0,557	0,045
7	0,968	0,074	0,888	0,081	0,954	0,080	0,625	0,051
8	0,888	0,068	0,097	0,009	0,929	0,078	0,922	0,075
9	1	0,077	0,554	0,050	0,097	0,008	0,818	0,067
10	1	0,077	0,869	0,079	0,944	0,079	0,435	0,035
11	0,908	0,069	0,913	0,083	0,948	0,079	0,956	0,078
12	0,601	0,046	0,199	0,018	0,097	0,008	0,911	0,074
13	0,052	0,004	0,954	0,087	0,868	0,073	0,887	0,072
14	0,052	0,004	0,098	0,009	0,954	0,080	0,954	0,078
15	0,912	0,070	0,884	0,080	0,981	0,082	0,917	0,075
16	0,052	0,004	0,888	0,081	0,873	0,073	0,869	0,071
17	1	0,077	0,946	0,086	0,094	0,008	0,405	0,033
$\sum E_i$	13,057		10,996		11,922		12,262	

Continues Table 5

	2014		**2015**		**2016**	
	E_i	w_i	E_i	w_i	E_i	w_i
1	0,394	0,035	0,394	0,034	0,067	0,007
2	0,933	0,083	0,895	0,076	0,954	0,099

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3	0,931	0,083	0,954	0,081	0,884	0,091
4	0,178	0,016	0,747	0,064	0,611	0,063
5	0,821	0,073	0,781	0,066	0,723	0,075
6	0,187	0,017	0,238	0,020	0,097	0,010
7	0,098	0,009	0,927	0,079	0,736	0,076
8	0,920	0,082	0,873	0,074	0,954	0,099
9	0,866	0,077	0,916	0,078	0,920	0,095
10	0,216	0,019	0,124	0,011	0,097	0,010
11	0,955	0,085	0,954	0,081	0,097	0,010
12	0,870	0,078	0,954	0,081	0,885	0,091
13	0,878	0.078	0,949	0,081	0,800	0,083
14	0,954	0,085	0,954	0,081	0,630	0,065
15	0,975	0,087	0,037	0,003	0,190	0,020
16	0,954	0,085	0,884	0,075	0,944	0,098
17	0,094	0,008	0,181	0,015	0,094	0,010
$\sum E_i$	11,224		11,762		9,683	

$$AESI_{2010} = \sum_{i=1}^{17} \mu''_{2010}(x_i) * w_{2010}(x_i) =$$

$0.052 * 0{,}077 + 0.6399498 * 0{,}058 + \cdots + 0.045614 * 0{,}0766 = 0{,}272698$

$AESI_{2011} = 0.372$

$AESI_{2012} = 0.347$

$AESI_{2013} = 0.405$

$AESI_{2014} = 0.353$

$AESI_{2015} = 0.325$

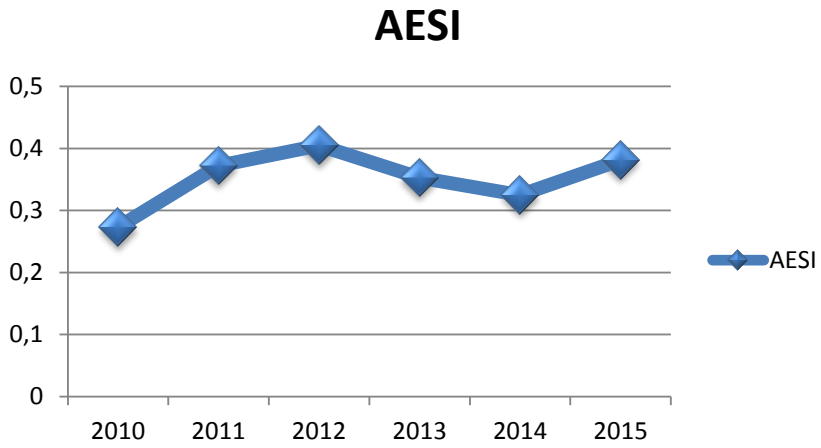

Fig. 1. Graphic of AESII indicators' dynamic of Azerbaijan for 2010-2016-th years

$$AESI_{2016} = \sum_{i=1}^{17} \mu''_{2016}(x_i) * w_{2016}(x_i) = 0.955 * 0.007 + 0.044 * 0.099 + \cdots + \cdots = 0.381$$

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Comparative analysis from 2010 to 2016 allows us to state that the value of the aggregate ecological security index has increased. At the same time, in 2010, the largest share among the negative factors was due to the following factors 7- Corner gas (CO2) = (0,04), 2- Population growth rate = (0,037), 3- Oil and natural gas production = (0,016)), 12- Polluting entrances emitted into the atmosphere (0,034). When analyzing the factors that had a positive impact on the environment in 2010, the most influential factor was 15 (0.039), while the rest were insignificant. In 2016, the most negative factors were 2 - Population growth rate = (0.0985), 8-Nitric oxide (N2O) = (0.0985), 9-Methane (CH4) = (0.0945) and 3 - oil and natural gas production = (0,091), 12- Production polluting emissions released into the atmosphere = (0,091), that is, the positions of factors 2, 3 12–remain in the 2016th year. For 2016For 2016, the positive factor is the factor 16-Cost of Science=(0.097). A factor 14 – reserves = (0,065) is much less valuable factor

An aggregated ESI score is interpreted by the definition of the 5 classes shown in table 6 below.

Table 6. An aggregated ESI

The value of index *ESI*	State of index *ESI*
More than 0.55	favorable
0.45-0.55	satisfying
0.40-0.45	stressful
0.35-0.40	critical
Less than 0.35	catastrophic

According to our calculations, the values of the aggregate environmental safety index AESI are in catastrophic condition in 2010, and in 2016 - in critical condition [7].

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