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Application of multi-criteria decision analysis to select the best waste management technology at the waste processing plant

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Abstract
One of the key elements in solving environment-protection problems is introducing the principles of the best available technologies, which are effective in evaluating and regulating the negative impact industrial plants have on the environment. The term “best available technologies” (BAT) are defined as the production technologies, processes and services, determined on the basis of modern science and technology, with the best combination of criteria to achieve environmental objectives subject to availability of technical possibilities being taken into account. The problem of selecting the best available technologies is based on the valuation of pollution and counter-pollution measures and the regulation of the negative impact of industrial production on the environment. Comparing alternative technological options is a complex task in which many environmental, technological, economic and social criteria should be taken into account. One of the main conditions for the correct selection of tools for decision making on BAT is to adequately address uncertain input data. For the correct assessment of alternative technologies including comparison of the levels of negative impacts on the environment, we propose a model of multi-criteria decision making with fuzzy parameters which is a variant of the fuzzy multicriteria decision making methodology called TOPSIS. A stepwise algorithm for multi-criteria decision-making is developed that allows us to operate with uncertain, fuzzy input data using subjective expert evaluations. The proposed method is illustrated with a real-life example which verifies and justifies the method, and illustrates its effectiveness and ability to provide an objective decision-making solution.

Keywords: environment, best available technology, environmental models, multi-criteria decision making, fuzzy sets theory

1. Introduction

The solution of environmental problems is based on the implementation of the sustainable development concept, i.e. long-term continuous development of society, providing the needs of people without compromising the needs of future generations. The main source of negative impact on the environment is industrial production. It is impossible to completely eliminate this impact, so it is important to apply rational principles and methods of environmental protection regulation, stimulating the rapid development of new environmentally friendly technologies [1]. One of the key elements in solving ecological and economic problems is the introduction the best available technologies (BAT), on the basis of which the regulation of industrial production activities that have a significant negative impact on the environment.

Currently, international standards are tightening requirements concerning ecology and safety of production processes [3]. Experience shows that the issuance of integrated permits for emissions, discharges and disposal of waste, based on the use of standards defined in accordance with BAT, is an effective tool and allows to minimize the main types of negative impact on the environment, as well as to update fixed assets, create energy-efficient and resource-saving production facilities, increase the competitiveness of industry. A critical challenge in BAT implementation is to determine which of the alternatives the best is. The comparison of technological alternatives is a complex task that must take into account numerous environmental, technological, economic and social criterions. The choice must take into account the impact on different components of the environment, the choice can be made between emissions or discharges to different environments.

The lack of evidence-based environmental decision-making methods makes this process much more difficult. Officially adopted methodologies today successfully work only in the simplest situations and can’t give a clear choice of alternative solutions in complex environmental problems.

2. Literature review

It should be noted that most publications disclose and clarify the main provisions of the General methodology for the selection of BAT, analyzes the experience of its application for various industries and enterprises. For the problem of determining BAT, the statement of the work [5] is true that the expansion of the Arsenal of instrumental and mathematical modeling tools belongs to the main directions of improving the quality of economic and mathematical models and increasing their efficiency in economic practice.

In work [6] on the basis of the system approach and with the use of the mathematical apparatus of the theory of sets the system model of BAT which allows to set uniformly and solve a problem of identification of technology for production of various chemical products is offered. In work [7] the characteristic of expert system of an assessment of ecological and economic efficiency of BAT and measurement of cost is presented intellectual labor as the main factor of this efficiency. The methodological approach to the definition of BAT is considered in the article [8].

There is a larger number of foreign publications devoted to the concept of BAT and the application of mathematical models and methods to select the best alternative. As noted in [9], the main approach to the definition of BAT is to use the methodology of analysis of multi-criteria decision-making.
Multicriteria decision-making offers a systematic approach for creating flexible methodologies and solving complex problems of choosing from several alternatives, each of which is evaluated by a large number of different criterions or factors and is accompanied by conflicts of views, interests and assessments.
Extensive review of the literature on BAT assessment and selection process presented in [12]. The study provides a holistic analysis of current trends in methods that can be applied at different stages of the process. The most widely used criteria, sources of information, mathematical methods that are used to compare options and select the best technological alternatives are identified.
In most cases, the decision-making process takes place in conditions of uncertainty, inaccurate information, when the goals, limitations, conditions of possible options for action are not exactly known. Traditionally, the stochastic approach is used. However, when it is impossible to set the distribution law of a random variable, and the uncertainty is also due to the qualitative nature of the parameters, it is necessary to use other means.
At the stage of comparing options and choosing the best alternative, the application of the fuzzy multicriteria decision-making procedure is justified, and its use is proposed in this paper. The development of methods of multicriteria decision-making has received a new direction with the advent of fuzzy sets theory. Fuzzy logic operates with levels of admissibility of the solution, which allows considering several alternative solutions to multicriteria problems and, if the conflict of ideas, interests and assessments is not clearly defined, but is soft, blurred, it allows to find compromises, as it gives the decision-maker a greater degree of freedom [14]. The General methodology of modeling is presented, for example, in [15-17] works.
In this paper a model of multicriteria decision-making with fuzzy parameters is represented as well, but in contrast to works, mentioned above, to solve the problem of determining BAT a fuzzy version of the method TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is offered.

3. Model of multicriteria decision-making

A key step in evaluating alternative technologies is to compare the levels of negative environmental impact. The first step in assessing BATs in terms of their environmental impact is to identify a set of alternative technologies that claim to be the best. The criterions are the characteristics defining each alternative - the levels of negative impact on the environment. The main goal is to select the optimal technological alternative that best ensures comprehensive prevention or minimization of negative environmental impact, i.e. the desired values of a set of criteria selected by the decision-maker. Each criterion has its own weight - relative importance in terms of environmental impact.
In order to define the technology as BAT, it is necessary to use expert evaluation. Experts can be representatives of executive authorities, scientific organizations, non-profit organizations, technical working groups, interested enterprises. Their estimates may vary. The proposed methodology of multicriteria decision-making involves the creation of a formal model and the use of fuzzy sets. There is a set of p alternative technologies. Each technology is evaluated according to n criteria. The decision-making process takes into account the views of m experts.
Each criterion is determined by the rating and weighing of criterion: w_{ij} — the weight estimation of the i-th criterion by j-th expert; rk_{ij} — score for the k-th technology of the i-th criterion by j-th expert; $k = 1, ... , p$; $i = 1, ... , n$; $j = 1, ... , m$

Table 1: Results of expert assessments

Technologies	Criterions	1					…	i					…	n				
	Experts	1	…	j	…	m	…	1	…	j	…	m	…	1	…	j	…	m
1	Scores	r111	…	r11j	…	r11m	…	r1i1	…	r1ij	…	r1im	…	r1n1	…	r1nj	…	r1nm
…		…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
k		rk11	…	rk1j	…	rk1m	…	rki1	…	rkij	…	rkim	…	rkn1	…	rkn1	…	rknm
…		…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
p		rp11	…	rp1j	…	rp1m	…	rpi1	…	rpij	…	rpim	…	rpn1	…	rpn1	…	rpnm
Weights		w11	…	wij	…	w1m	…	wi1	…	wij	…	wim	…	wn1	…	wn1	…	wnm

Quantitative indicators (r_{kij} values) can be obtained from monitoring data at existing similar production facilities, reporting materials, experimental and calculated data, information from suppliers or manufacturers of equipment. Given the different sources of information, the accuracy of the data can't be considered absolute. The probabilistic approach is not applicable in this case, since the laws of distribution of random variables are usually unknown. At the same time, it is possible to determine the minimum, maximum and most possible values of the indicators, which allows us to offer a natural adequate representation of the parameters by fuzzy numbers.
Quantitative indicators of input and output streams have different dimensions, so a normalization process is needed to compare alternatives, which will lead them to a comparable form. For this purpose, the standard linear scaling method implemented for the case of fuzzy quantities can be applied.
The definition of weighted factors is subjective and requires the agreement of experts (m). The most realistic approach to expressing preferences is to use verbal statements instead of numerical values [31]. The significance of the criteria can be described in terms of fuzzy sets and represented by linguistic variables. To describe such variables, triangular membership functions defined on the universal set represented by the interval [0, 1] will be used. Aggregation of expert opinions, i.e. generalization of the w_{ij} weights, taking into account the opinions of all experts, can be made using fuzzy weighted aggregation operators [14]. To determine BAT in an adequate way, a solution of using fuzzy option of the TOPSIS method. The concept of the TOPSIS method is that the best alternative should be the closest to the ideal solution and the farthest from the negative ideal solution [32]. Distance measure is a term that defines the difference between fuzzy sets, there are different ways to define it. For triangular fuzzy numbers the method proposed in [32] will be used.

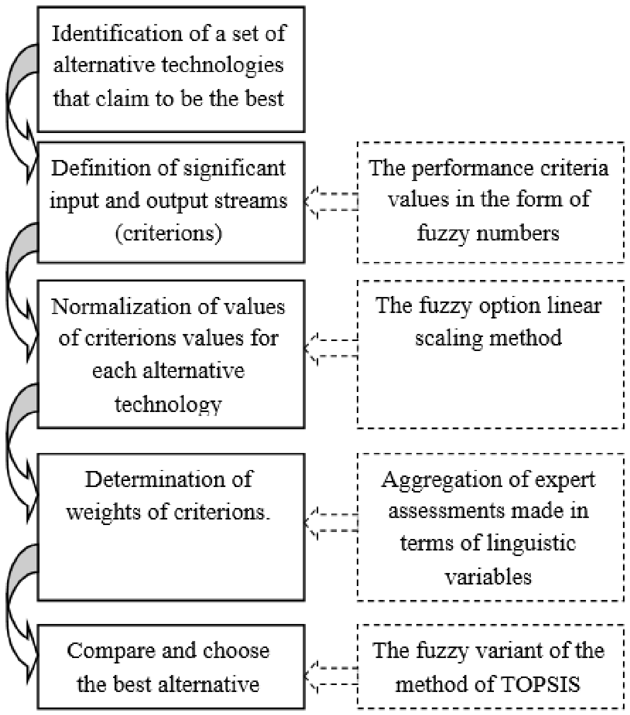

Fig 1: Scheme of comparison of alternative technologies by levels negative impact on the environment.

4. Method for solving the problem of BAT selection by the criterion of the level of negative impact on the environment

Step 1. Evaluation of the *i*-th criterion is made by the *j*-th expert for the technology *k* with the indication of the minimum $r_{(min)kij}$; maximum $r_{(max)kij}$; and the most possible $r_{(pos)kij}$ values of the corresponding flow displayed in a fuzzy triangular number:

$$r_{kij} = \left(r_{kij}^{min}, r_{kij}^{pos}, r_{kij}^{max}\right); k = 1, \ldots, p; i = 1, \ldots, m \quad (1)$$

Step 2. Experts' estimates must be generalized in order to obtain a single estimate of $\underline{r}_{ki}$.

$$\underline{r_{ki} = (r_{ki1} + \ldots + r_{kim})} \over m; k = 1, \ldots, p; i = 1, \ldots, n. \quad (2)$$

Step 3. To normalize the values of $\underline{r}_{ki}$ the method of linear scaling is applied. Maximum value for all technologies is defined for each criterion *i*:

$$N_i = \max\{r_{ki} \mid i = 1, \ldots, n \mid k = 1, \ldots, p\} \quad (3)$$

The minimum value corresponds to no flow, i.e. zero flow. Normalized values are defined as follows:

$$R_{ki} = \frac{r_{ki}}{N_i} i = 1 \ \ldots, n \ ; \ k = 1, \ldots, p \quad (4)$$

Step 4. Expert assessments are also summarized to determine the weights of the criteria. Evaluation of the weight of criterion *i* is carried out by expert *j* in qualitative form using the value of a linguistic variable selected from the termset *T* (weight of criterion) and displayed in the fuzzy number w_{ij}, $i = 1, \ldots, n$; $j = 1, \ldots, m$.

$$w_i = \frac{(w_{i1} + \ldots + w_{im})}{m}; i = 1 \ \ldots, n \quad (5)$$

Step 5. A condition for a comprehensive assessment taking into account weights is their rationing. By extending this condition to the case of fuzzy weights, we obtain normalized fuzzy weights:

$$W_i = \frac{w_i}{(w_1 + \ldots + w_n)} \ ; i = 1 \ \ldots, n \quad (6)$$

Step 6. As a result, a complex assessment of the negative impact on the environment of *k*-th technology in the form of a fuzzy number is defined:

$$N_k = W_1 R_{k1} + \ldots + W_n R_{kn} \ ; i = 1 \ \ldots, n \ ; k = 1, \ldots, p \quad (7)$$

Since we use triangular fuzzy numbers, another form of notation is as follows:

$$N_k = (N_k^{\ min}, N_k^{\ pos}, N_k^{\ max}) \quad (8)$$

Step 7. To compare the alternatives and choose the best one using the fuzzy variant of the TOPSIS method it is necessary to determine the ideal solution N^+ and negative one N^-. The ideal solution corresponds to zero values of flows, i.e. complete absence of negative impact $N^+ = 0$. The negative ideal solution will be considered to be the variant with the worst (maximum) values of flows in the system for each criterion of all alternatives, $i = 1 \ldots, n$. Respectively: $N = W_1 N_1 + \ldots + W_n N_n$.

Step 8. For each technology $k = 1, p$ a measure of the distance of the complex estimation N_k from the ideal solution $N^+ = (N^{+min}, N^{epos}, N^{+max})$ and negative ideal solution $N^- = (N^{-min}, N^{-pos}, N^{-max})$:

$$d(N_k, N^+) = \sqrt{\left(\frac{1}{3}\left[(N^{+min} - N_k^{min})^2 + (N^{+pos} - N_k^{pos})^2 + (N^{+max} - N_k^{max})^2\right]\right)} \quad (9)$$

$$d(N_k, N^-) = \sqrt{\left(\frac{1}{3}\left[(N^{-min} - N_k^{min})^2 + (N^{-pos} - N_k^{pos})^2 + (N^{-max} - N_k^{max})^2\right]\right)} \quad (10)$$

Step 9. Let's define the coefficient of proximity of each alternative with the worst solution.

$$CC_k = \frac{d(N_k, N^-)}{d(N_k, N^-) - d(N_k, N^+)} \ k = 1, \ldots, p \quad (11)$$

The proximity coefficient is in the range [0, 1]. The greater its value, the better the alternative technology in terms of minimizing the negative impact on the environment. Thus, the order of ranking of alternatives can be defined and the best technology among the many possible alternatives with the highest value can be chosen:

$$CC_b = \max\{CC_k \mid k = 1, \ldots, p\} \quad (13)$$

5. Key study

Let's explain the proposed method by example production of lime, limiting the technology selection procedure to the assessment of emissions of pollutants into the atmosphere and consideration of four alternative technologies.

The technological process of lime production consists of the following stages: crushing and grinding; sorting, transportation and dosing; kiln firing; lime quenching. Dust formation occurs during the operation of the main technological equipment at all stages: roasting furnaces, crushers, screens, mills; during the operation of technological transport: conveyors, augers, feeders; during loading and unloading operations, etc. Various types of furnace are used for calcination of the raw material. Substances that characterize the chemical composition and dustiness of gases at the outlet of the furnace, the physical and chemical properties of raw materials and fuel, the operation of cleaning equipment and losses should be taken as marker pollutants in the production of lime [34]. Marker pollutants are: inorganic dust containing silicon dioxide, nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), carbon (soot (C)), sulfur dioxides (SOx). Depending on the design of the furnace and the fuel used, the temperature parameters, as well as the quantitative and qualitative composition of emissions of pollutants into the air vary.

Technology 1. Conventional mine furnaces are used for calcination of limestone and obtaining lime. The heat to displace CO_2 from $CaCO_3$ is supplied to the furnace from solid fuel, which is loaded into the furnace along with limestone, and from natural gas, which is supplied to the furnace through a built-in central burner. The exhaust gas is pumped out in the furnace head and enters the atmosphere through the filter unit and the purified gas pipe.

Technology 2. A rotating furnace is used for firing, the raw material from the dryer enters the furnace through the chamber of the cold end of the furnace, chalk is used as the raw material. The furnace is gradually heating raw materials and decays CaCO3 to CO2 and CaO. Adjusting the speed and temperature of the combustion products may affect the type of lime firing. The rotary kiln is heated using a furnace burner and natural gas. De-dusting of the furnace line is carried out by a dust collector, which consists of a fabric filter and a radial fan that provides extraction of hot exhaust gases from the furnace line.

Technology 3. A rotary kiln with a baking heat exchanger is used for firing a rotary kiln with a baking heat exchanger and dolomite is used as a raw material. The rotary kiln is heated using a furnace burner and natural gas. De-dusting of the furnace line is carried out by a dust collector, which consists of a fabric filter and a radial fan that provides extraction of hot exhaust gases from the furnace line.

Technology 4. Bulk mine furnaces are used for roasting, dolomite is used as raw material. Heating is carried out by solid fuel, which is loaded into the furnace along with dolomite, and by natural gas, which is supplied to the furnace through the built-in central burner. The exhaust gas is pumped out in the furnace head and enters the atmosphere through the filter unit and the purified gas pipe.

Information on the four alternative technologies identified by the three experts is presented in the Table 2. In Table 3 the generalized emission values and their normalized values for each technology are given in the form of fuzzy numbers. Table 4 contains the linguistic scores of each expert (j) for each criterion (i) of the weights of the criteria (M); displaying the scores in fuzzy numbers (w_{ij}); generalized expert estimates as a fuzzy number (w_i); normalized fuzzy weights of criteria (W_i). Term-set of linguistic estimates of criterions' weights for this example is defined is as follows: T (criterion weight) = {low; moderate; high; extremely high}.

The functions of belonging to the values of a linguistic variable are shown in Figure 2 and simplistically can be defined as sets of ordered pairs:

M (low) = {(0, 1; 0, 5), (0, 2; 1), (0, 3; 0, 5)};

M (moderate) = {(0, 3; 0, 5), (0, 4; 1), (0, 5; 0, 5)};

M (high) = {(0, 5; 0, 5), (0, 6; 1), (0, 7; 0, 5)};

M (extremely high) = {(0, 7; 0, 5), (0, 8; 1), (0, 9; 0, 5)}.

This data can be displayed in fuzzy numbers (0; 0, 2; 0, 4); (0, 2; 0, 4; 0, 6); (0, 4; 0, 6; 0, 8); (0, 6; 0, 8; 1) accordingly.

Table 2: Indicators of pollutants' emissions into the air

Substance	Criterions *i*	Experts *j*	Technology 1			Technology 2			Technology 3			Technology 4		
			k											
			Emissions, mg / m3											
			min	most possible	max	min	most possible	max	min	most possible	max	min	most possible	max
Dust (inorganic, containing silicon dioxide)	1	1	80	130	180	120	146	172	5	82	160	10	55	100
		2	115	124	133	145	151	158	82	84	86	38	59	81
		3	117	120	124	145	151	157	83	83	84	57	60	64
Nitrogen dioxides (NO*x*)	2	1	300	325	350	100	125	150	100	1050	2000	10	1005	2000
		2	324	334	345	105	122	140	119	918	1717	617	1193	1770
		3	330	336	342	115	119	124	199	617	1035	1091	1171	1251
Carbon monoxide (CO)	3	1	750	1375	2000	150	475	800	40	1470	2900	10	1255	2500
		2	799	1316	1834	364	536	709	1423	1846	2270	190	1249	2308
		3	800	1191	1583	466	503	541	1520	1869	2218	787	1482	2177
Carbon Black (C)	4	1	0,5	0,65	0,8	0	0	0	0,2	55,1	110	1	50	100
		2	0,51	0,63	0,74	0	0	0	1,94	50,1	98,3	27	56	86
		3	0,58	0,6	0,63	0	0	0	19,8	48,8	77,7	48	53	59
Sulfur dioxide (SO)	5	1	150	155	160	0	0	0	5	752	1500	1	750	1500
		2	152	153	155	0	0	0	379	889	1399	365	831	1297
		3	152	152	153	0	0	0	-	-	-	680	846	1012
Chloride hydrogen (HCl)	6	1	0	0	0	0	0	0	0,1	20	40	0,1	20	40
		2	0	0	0	0	0	0	18,5	20,4	22,3	0,97	13,8	26,6
		3	0	0	0	0	0	0	19,9	21	22,1	13	17,6	22,2
Fluoride hydrogen (HF)	7	1	0	0	0	0	0	0	10	25	40	0	0	0
		2	0	0	0	0	0	0	20	28	37	0	0	0
		3	0	0	0	0	0	0	28	28	29	0	0	0

Table 3: Generalized experts' estimates and their normalized values for emission indicators

k	1			2			3			4	
z_{ki}	104,00	124,67	145,67	**136,67**	**149,33**	**162,33**	58,67	83,00	110,00	35,00	58,00
R_{ki}	0,64	0,83	1,07	**0,84**	**1,00**	**1,19**	0,35	0,56	0,80	0,22	0,39
z_{ki}	318,00	331,67	345,67	106,67	122,00	138,00	139,33	861,67	1584,00	**572,67**	**1125,00**
R_{ki}	0,18	0,30	0,60	0,08	0,11	0,24	0,08	0,77	2,77	**0,34**	**1,00**
z_{ki}	783,00	1294,00	1805,67	326,67	504,67	683,33	**994,33**	**1728,33**	**2462,67**	329,00	1328,67
R_{ki}	0,32	0,75	1,82	0,13	0,29	0,69	**0,40**	**1,00**	**2,48**	0,13	0,77
z_{ki}	0,53	0,63	0,72	0,00	0,00	0,00	**7,31**	**51,33**	**95,33**	25,33	53,00
R_{ki}	0,01	0,01	0,10	0,00	0,00	0,00	**0,08**	**1,00**	**12,99**	0,27	1,03
z_{ki}	151,33	153,33	156,00	0,00	0,00	0,00	128,00	547,00	956,33	**348,67**	**809,00**
R_{ki}	0,12	0,18	0,45	0,00	0,00	0,00	0,10	0,68	2,77	**0,27**	**1,00**
z_{ki}	0,00	0,00	0,00	0,00	0,00	0,00	**12,83**	**20,47**	**28,13**	4,69	17,13
R_{ki}	0,00	0,00	0,00	0,00	0,00	0,00	**0,46**	**1,00**	**2,19**	0,17	0,83
z_{ki}	0,00	0,00	0,00	0,00	0,00	0,00	**20,33**	**27,00**	**35,33**	0,00	0,00
R_{ki}	0,00	0,00	0,00	0,00	0,00	0,00	**0,55**	**1,00**	**1,83**	0,00	0,00

Table 4: Evaluation of criteria weights

i	*j*	*M*	*wij*	*w̲i*			*Wi*		
1	1	Moderate	0,2;0,4;0,6	0,27	0,47	0,67	0,06	0,15	0,37
	2	High	0,4;0,6;0,8						
	3	Moderate	0,2;0,4;0,6						
2	1	High	0,4;0,6;0,8	0,27	0,47	0,67	0,06	0,15	0,37
	2	Moderate	0,2;0,4;0,6						
	3	Moderate	0,2;0,4;0,6						
3	1	Low	0;0,2;0,4	0,07	0,27	0,47	0,02	0,08	0,26
	2	Low	0;0,2;0,4						
	3	Moderate	0,2;0,4;0,6						
4	1	Moderate	0,2;0,4;0,6	0,2	0,4	0,6	0,04	0,12	0,33
	2	Moderate	0,2;0,4;0,6						
	3	Moderate	0,2;0,4;0,6						
5	1	Moderate	0,2;0,4;0,6	0,27	0,47	0,67	0,06	0,15	0,37
	2	High	0,4;0,6;0,8						
	3	Moderate	0,2;0,4;0,6						
6	1	High	0,4;0,6;0,8	0,4	0,6	0,8	0,09	0,19	0,44
	2	High	0,4;0,6;0,8						
	3	High	0,4;0,6;0,8						
7	1	High	0,4;0,6;0,8	0,33	0,53	0,73	0,07	0,17	0,40
	2	Moderate	0,2;0,4;0,6						
	3	High	0,4;0,6;0,8						

In Table 5 comprehensive assessments of the negative impact of each *k*-th technology according to step 6 of the algorithm described earlier.

Table 5: Comprehensive assessment of negative impact

i	*k*	1			2			3			4		
1	*Wi Rki*	0,04	0,12	0,39	0,05	0,15	0,44	0,02	0,08	0,30	0,01	0,06	0,22
2	*Wi Rki*	0,01	0,04	0,22	0,00	0,02	0,09	0,00	0,11	1,02	0,02	0,15	1,08
3	*Wi Rki*	0,00	0,06	0,47	0,00	0,02	0,18	0,01	0,08	0,64	0,00	0,06	0,61
4	*Wi Rki*	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,12	4,31	0,01	0,13	3,69
5	*Wi Rki*	0,01	0,03	0,17	0,00	0,00	0,00	0,01	0,10	1,03	0,02	0,15	1,35
6	*Wi Rki*	0,00	0,00	0,00	0,00	0,00	0,00	0,04	0,19	0,97	0,01	0,16	1,02
7	*Wi Rki*	0,00	0,00	0,00	0,00	0,00	0,00	0,04	0,17	0,74	0,00	0,00	0,00
Nk		0,06	0,26	1,29	0,06	0,19	0,71	0,12	0,85	9,00	0,08	0,70	7,96

The ideal solution is defined as:

$N^{+} = (N^{+min}, N^{+pos}, N^{+max}) = (0; 0; 0)$.

The negative ideal solution is defined as a variant with the worst (maximum) values of N_i flows for each criterion (highlighted in Table 3) taking into account their weights:

$N^{-} = (N^{-min}, N^{-pos}, N^{-max}) = (0, 18; 1, 01; 9, 53)$.

The distances of the complex estimation of each technology from the ideal solution, defined as d (N_k, N^{+}) and the negative ideal solution d (N_k, N^{-}) as well as the proximity coefficients CC*k* are presented in Table 6.

Table 6: Distances from ideal and negative ideal solutions, proximity coefficients

k	1	2	3	4
d (Nk , N+)	0,76	0,42	5,24	4,63
d (Nk , N-)	4,77	5,11	0,32	0,93
CCk	**1,19**	1,09	0,07	0,25

As a result, it was found that the best alternative technology is number 1.

6. Discussion, recommendations and conclusion

The research has shown the importance of qualitative assessment of BAT in the field of lime production technologies, the importance of using TOPSIS method in the case of fuzzy numbers. This method helps to evaluate technologies according to their impact on the environment and also helps managers to make correct decisions on which of the alternatives to use.

The problem of determining the best alternative to BAT is considered. The choice of BAT is complicated by the existence of numerous criterions, for which there is no clear preference for any technology; the lack of accurate data on the characteristics and potential impacts of technologies on the environment and the need use expert assessment.

For this problem, the representation of parameter values in the form of fuzzy numbers is justified, a fuzzy version of the linear scaling method, a method for aggregating expert estimates made in terms of linguistic variables, and a fuzzy version of the TOPSIS method is proposed. Illustration of the developed method on a real example shows its effectiveness and ability to provide objective decision-making in determining BAT in conflict situations. This article solves the problem of evaluating alternative technologies by the levels of negative impact on the environment from the significance point of view.

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