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FUZZY MULTIPLE CRITERIA ASSESSMENT OF CONSTRUCTION SITE ALTERNATIVES FOR NON-HAZARDOUS WASTE INCINERATION PLANT IN VILNIUS CITY, APPLYING ARAS-F AND AHP METHODS

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Abstract. Continuous increase in electricity and heat prices for citizens necessitates new alternative solutions regarding rational application of existing resources, in order to minimize electric energy production costs. The article presents the description of waste incineration plant siting issue, related to satisfaction of requirements formulated by investors, citizens, contractors and other concerned parties. As the siting process represents fulfilment of the above-stated stakeholder requirements, the multiple criteria task is defined. Seven local assessments of alternative sites located in densely populated urban and industrial development areas have been evaluated. The results of calculations show that the above industrial equipment units cover economic, social and environmental aspects. It was found that the most appropriate place for construction of waste incineration plants is the Paneriai industrial area. Densely populated urban districts can be referred to as the most improper location for waste incineration. The best results can be gained applying complex AHP and ARAS-F methods.

Keywords: waste incineration, alternative energy, AHP method, ARAS-F method, construction site selection, waste management technologies.

1. Introduction

In most countries with increasing population, prosperity and urbanization, one of the major challenges for municipalities is to collect, recycle, treat and dispose of increasing quantities of solid waste (Cherubini *et al.* 2009). Technological and social growth forms social preferences aimed at minimization of non-renewable sources and energy consumption, and pollutant emission to the environment. Protection of underground water and fertile soil layers is also encouraged (Morselli *et al.* 2008).

As generated domestic and construction waste cannot be removed automatically, it necessitates the development of a system and technologies for waste disposal, storage and proper application (Pavlas, Touš 2008). It is essential to understand, that the generated waste is not useless rubbish. Waste is an appropriatable energy source, which is continuously created by consumers (Tehrani *et al.* 2009).

The life cycle of waste includes handling systems based upon solutions regarding preservation of non-renewable sources (Cherubini *et al.* 2009). The life cycle of waste can be considered according to the alternatives of generated non-hazardous waste utilization: waste incineration, segregation and accumulation at disposal dumps. A selected waste utilization alternative determines the order of waste management processes and enables the assessment of the waste reuse efficiency in terms of economic, social and environmental aspects (Kaufman *et al.* 2010, Christensen *et al.* 2007). Waste processing, utilization and recycling is to a certain extent limited by many factors, and this inevitably encourages waste disposal in landfills (Jaskelevičius, Lynikienė 2009).

A standard generated-waste-handling system covers collection, transportation and processing as well as final utilization of residual materials (Dembiras 2011). Evaluation of the European Union member states, which are described as Advanced Economies (Grosso *et al.* 2010), revealed a great split between them in the field of technological progress in waste incineration. This can be explained by the fact, that construction of the first waste incineration plant in Lithuania (Klaipeda), which will centrally generate heat and electric energy, has been started in the second quarter of the year 2011.

Siting a solid waste incineration plant requires a comprehensive evaluation to identify the best available location that can simultaneously meet requirements of regulations and minimize economic, environmental, health, and social costs (Tavares *et al.* 2011; Moeinaddini *et al.* 2010). The use of multiple criteria analysis methods in solid waste management has the advantage of rendering subjective and implicit decision making more objective and analytical, with its ability to accommodate both quantitative and qualitative data (Ekmekcioglu *et al.* 2010; Pires *et al.* 2011).

The aim of the research is to present options for selection of the alternative solution regarding the siting of the waste incineration plant, which will comply with requirements of investors, citizens and other stakeholder groups. In order to assess the influence made by needs of concerned groups, the AHP (analytical hierarchy process) method was used to determine criteria of the key importance and to obtain the weighting (w_i) of each criterion (Podvezko *et al.* 2010; Yan *et al.* 2011). The AHP method has useful tools to help support a decision in convention site selection (Medineckienė *et al.* 2010). For selection of the most efficient alternative, the Fuzzy Additive Ratio Assessment (ARAS-F) method is applied.

2. Waste utilization possibilities

All production processes are justified by consumption of a particular energy type (extraction, transportation, thermal and mechanical treatment) in order to achieve stated results. Utilization of different resources that undergo financial evaluation creates products, including both the product and its package. Impossibility to assimilate all provided advantages of the product leads to waste generation, and all in all to the loss of the initial investment in the product creation (Roussat *et al*. 2009). For example, utilization of secondary raw materials saves 200 GJ of energy per 1 ton of produced aluminium products. The above amount represents more than 95% of energy costs saving in comparison with the production of aluminium using primary resources (Thormark 2001).

Evaluation of Danish waste incineration technology confirmed the use of already constructed incineration plants for generated waste incineration (Fruergaard *et al.* 2010). In his scientific publication, Fruergaard provided the results achieved by application of waste incineration technologies (Table 1).

Data in Table 2 proves the urgency of waste (domestic, construction, demolition and etc.,) and energy utilization in leading European countries. Main aspects for energy generation and justification of materials processing are environmental protection (Ragossnik *et al.* 2009; Zhang *et al.* 2011), economic benefits (Coelho, Brito 2010), possibility to improve social conditions, increase exports and create new jobs, etc.

Table 1. Danish results at waste incineration plants

		System case	
		Aarhus	Herning
Made energy in 2007 year (10^{12} J)		10590	2650
Fuels used by the main supplier (energy based)		Coal 91%, straw 7%, heavy fuel oil 2%	Wood chips 75%, natural gas 22%, heavy fuel oil 3%
Input			
Waste	kg	1000	1000
Natural gas	m³	0	25
Electricity from grid	kWh	75	124
Heat from network	kWh	6	3
Output			
Produced electricity	kWh	587	712
Produced heat	kWh	2083	2813

Table 2. The use of waste in the European Union in 2010

Country	Electricity produced by combustible renewables and waste generation [GWh] (1)*	Municipal waste in 2010 [10^3 t] (2)*	Quantity of incineration plants in Europe (Grosso *et al.* 2010)
Lithuania	89.0	1044.0	–
Belgium	5004.3	5171.1	18
Denmark	3988.7	4270.2	34
Austria	6140.3	4690.9	9
Sweden	12771.0	4696.9	30
Finland	9202.8	2596.3	1
Germany	47279.8	48090.3	68
Italy	8081.0	32921.4	51

* (1–2) Source: Euromonitor International from OECD 2010.

Thermal treatment of solid waste is believed to be most efficient waste utilization method, based on heat and electric power recovery benefits. Waste becomes alike with continuously generated fuel, constant recovery of which ensures the possibility to control waste generation and obtain economic benefit (Pavlas, Touš 2008). Waste incineration is an integral part of the national waste market, thus, it is essential to develop waste management systems and ensure a possibility to control waste streams. The operated system evaluates all costs related to waste collection, logistics and initial investments to incineration plants as well as Project results.

3. Determination of Project implementation areas and estimation of evaluation criteria

Incineration plants are assessed according to the wide range of criteria justified by sets of requirements for environmental protection and ecology, by social attitude, economic benefit, required investments and their return, architectural cultural norms of the City, and possible technological solutions for Project implementation. All requirements of concerned groups will be evaluated and the most sufficient solution will be found, in order to determine the site for construction of the waste incineration plant (Aragones-Beltran *et al.* 2010). So, the above task will be resolved considering engineering, social and urban factors (Table 3).

Engineering factors include a part of investments required for project development. Domestic buildings, offices, production and public sector buildings cannot operate without utilities. While considering facilities, production of heat and electric energy and already produced energy will be directed to distribution networks, in order to supply energy to its end-users. Transfer pipelines and electric mains can be used for this purpose. For initiation of incineration process or its maintenance, fossil fuel (conventional gas) or electric energy will be provided (Fruergaard *et al.* 2010). Design of water supply systems will include systems intended for spent water removal.

Precipitation cannot be directed to the urban sewage network, because rain water can mix with formed waste and the whole mixture could impede on the operation of water treatment facilities.

Table 3. Alternative assessment factors

	Engineering factors:
x_1	Distance to centralized heating network mains (Ø400), km
x_2	Distance to the high-pressure (12 bar) gas supply pipeline (Ø150), km
x_3	Distance to 110 kW electric supply networks, km
x_4	Distance to water supply networks (Ø110), km
x_5	Distance to domestic sewage networks (Ø110), km
x_6	Distance to the rainwater sewage network (Ø110–200), km
	Urban factors:
x_7	Distance to the Vilnius city centre, km;
x_8	Total area of the required access roads, ha (Vilnius region…2010)
	Social factors:
x_9	Average number of people living on the territory of the determined alternative, 1 km^2
x_{10}	Usable area of apartments owned by people living in the territory intended for project implementation, m^2

* Ø – pipe diameter, mm

Urban factors describe the position of an incineration plant in terms of urban development. The distance to the city centre evaluates the location of an incineration plant and considers the possible impact on architecture of the city, due to the precise cultural style of the centre and adjacent quarters. Constructions of the present type differ from the architectural style of the city, thus should be located as far away from the living environment of citizens as possible. All factors are essential for the selection of energy production technology, which can cause different inconveniences such as noise, odour or aesthetic view.

The total area of required access roads creates the necessity to develop the urban infrastructure. During the development, existing roads can be adapted. Still, green areas, recreation objects or other areas intended for public purposes (e.g. parks or woods) will be used in order to construct new access roads.

Social factors represent the general evaluation of public interests. Evaluation of the public average value per 1 km^2 distributed within the territory for construction of the proposed incineration plant estimates the number of citizens to be settled near the power plant. The above factor describes the number of people to be able to offer their opinion concerning the Project implementation. Selection of appropriate technological solutions within the incineration plant during the construction process will ensure that citizens are protected from negative influence of hazardous actions or offensive odour, appearing during the operation of the plant; still, attitude of the public can disturb the Project implementation process. During the Project assessment, opinion of the public was considered and it was observed that the site, selected for the Project implementation should have the smallest density of population. Assessing the Project from the point of view of the state or a private investor, it is rational to construct a power plant in a densely populated territory to ensure energy needs.

Usable area of apartments owned by citizens shows the area to be supplied with the energy generated by the new energy facility. The above factor is useful both for social and production design processes: evaluated future usable are of apartments can be used to design the capacity of a plant to be needed for provision of energy to all accessible consumers.

For waste incineration plant siting in the Vilnius city (Lithuania), seven alternatives are foreseen (Fig. 1). Alternatives are selected according to the data, specified in the feasibility study "Development of Vilnius Regional Waste Management Infrastructure".

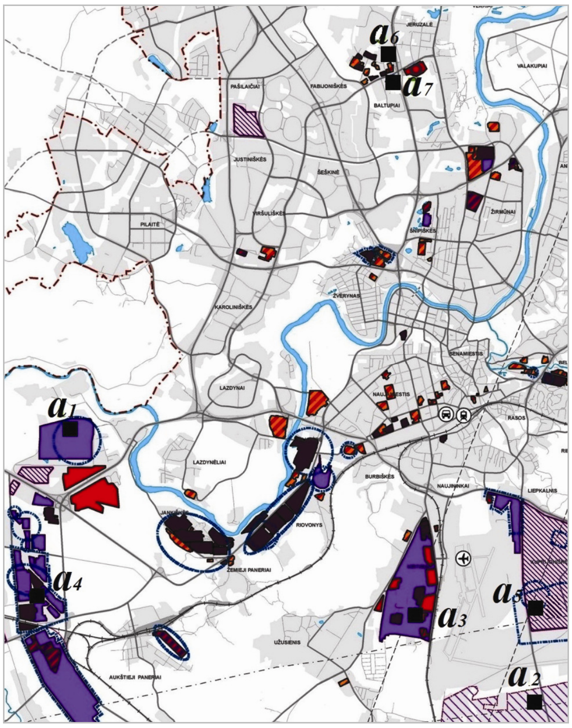

Fig. 1. Plan showing the distribution of alternatives (a_1, a_2, a_3, a_4, a_5, a_6, a_7) *in* Vilnius city (The Master Plan... 2010)

4. Determination of factor significance applying analytical hierarchy process (AHP) method

The Analytical Hierarchy Process (AHP) is a multi-criteria decision making (MCDM) method that helps a decision-maker faced with complex problems containing multiple conflicting and subjective criteria (e.g. location or investment selection, project ranking and etc) (Ishizaka, Labib 2011). A popular twin comparison method called AHP, which was offered by Saaty (2000) and Saaty *et al*. (2003), has been widely used. Twin comparisons enable to increase compatibility of evaluations.

In the real world, problems are numerous and it is very difficult to extract precise data pertaining to measurement factors since all human preferences are prone to a degree of uncertainty (Heo *et al.* 2010). Decision-makers are also inclined to favour words over exact numbers when assessing criteria and alternatives. The AHP method allows the utilization of linguistic variables (Kaya, Kahraman 2011).

The AHP method enables to identify one level hierarchy indicators significance (importance) in terms of a higher level or hierarchically non-structured significance of indicators. The essence of the method lies in the twin-comparison matrix (Sivilevičius 2011; Sivilevičius, Maskeliūnaitė 2010; Maskeliūnaitė *et al.* 2009). A hierarchy constructing a problem with several levels must first be structured (Lin 2010)

Citizens, potential investors, specialists of environmental protection, architects and construction contractors were interviewed, in order to determine the attitude of concerned groups towards the site for construction of the waste incineration plant. Five representatives of concerned groups were interviewed. Representatives of the above-state groups assessed the stated factors (Table 3) according to the Saaty (Saaty 1980) scale. Group decision making involves aggregation of diverse individual preferences to obtain a single collective preference. Such aggregation is extremely difficult as opinions may be conflicting (Jaskowski *et al.* 2010).

In the field of decision-making, the concept of priority is quintessential and how priorities are derived influences the choices one makes (Fouladgar *et al.* 2011). Priorities should be unique and not one of many possibilities, they must also capture the dominance of the order expressed in the judgments of the pairwise comparison matrix. The idea of a priority vector has much less validity for an arbitrary positive reciprocal matrix $A = (a_{ij})$ than for a consistent and a near consistent matrix (Saaty 2003). In the AHP, the decision matrix is always a square matrix (Turskis, Zavadskas 2010; Aguilar-Lasserre *et al.* 2009):

$$A = \left(a_{ij}\right) = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_m} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_m} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_m}{w_1} & \frac{w_m}{w_2} & \cdots & 1 \end{bmatrix}, \quad (1)$$

$$a_{ii} = 1, a_{ij} = \frac{1}{a_{ji}}, a_{ij} \neq 0.$$

Assessments of all five representatives are used for calculations applying the AHP method (Table 4) (Sivilevičius 2011). Ultimate calculation results allow determining factor significance which will apply in selection of the alternative. The gained results in Table 4 are varying (Fig. 2), that is why further calculations will be performed on the basis of minimum ($\omega_i \in \omega_{i,\alpha} = \omega_{\min}$) factor significance, median ($\omega_i \in \omega_{i,\beta} = \omega_{mediana}$) and maximum ($\omega_i \in \omega_{i,\gamma} = \omega_{\max}$) significance.

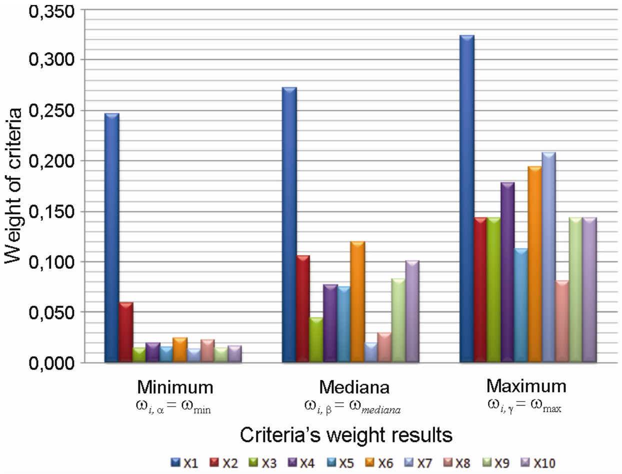

Fig. 2. Variation of criteria weights

When determination of factor significance is done, the further estimation concerning the consistency of matrixes, developed by specialists and consistency of their attitudes is performed.

Inverse second-order symmetrical matrices are always consistent. The relationship between the calculated consistency index S_I of a particular matrix and the average random index value S_A is referred to as consistency relationship. The value of consistency index S – which is smaller than or equal to 0.1 – is acceptable, implying that the matrix is consistent (Podvezko 2009; Podvezko *et al.* 2010) (Table 5).

5. Problem solving with the help of the Fuzzy Additive Ratio Assessment (ARAS-F) method

In most real cases, crisp human judgements are vague and cannot be expressed in exact numeric values. Human thinking and actions deal with the ill-structured decision problems in an uncertain environment. Human decision making should take into account subjectivity. Fuzzy set theory allows decision makers to use incomplete or partially obtained information into the problem solving model (Turskis and Zavadskas 2010).

Various types of membership functions are used. The most commonly used membership functions are the following: triangular, trapezoid, linear, π-type and Gaussian. The most typical fuzzy set membership function is the triangular membership function (Fig. 3) (Dubois, Prade 1988).

μ_A *is* the membership function of the fuzzy set matrix *A,* considering that $\mu_A(x) \in [0,1]$ and is defined as:

$$\mu_A(x) = \begin{cases} \frac{x-\alpha}{\beta-\alpha}, & \alpha \le x \le \beta, \\ \frac{x-\gamma}{\delta-\gamma}, & \beta \le x \le \gamma, \\ 0, & x > \gamma. \end{cases} \quad (2)$$

Table 4. Calculation sequence and results of eigenvector ω

Calculating step	Expert	Criteria number									
		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
Step I		ω''_1	ω''_2	ω''_3	ω''_4	ω''_5	ω''_6	ω''_7	ω''_8	ω''_9	ω''_{10}
Calculated elements a_{ij} of all Experts		$\omega''_i = \prod_{j=1}^{10} a_{ij}$									
Each row multiplication	1	510300	128	0.300	19440	192	46656.0	5.95E-07	6.20E-05	2.38E-07	0.033
	2	3307500	1.2	0.001	1.8	1.5	157.5	5184	3	1.76E-04	2.45E-07
	3	1607445	2304	2304	0.80	5.02E-07	3.67E-05	4.52E-06	0.0003	2304	2304.0
	4	408240	32	0.005	10.5	48	48	3.08E-08	5.51E-06	192	19.7
	5	907200	0.27	1.28E-07	2.83E-06	1.06E-04	1344	75600	0.27	7.88	504
Step II		ω'_1	ω'_2	ω'_3	ω'_4	ω'_5	ω'_6	ω'_7	ω'_8	ω'_9	ω'_{10}
n degree root is calculated from each row calculated ω''_i. (n = 10)		$\omega'_i = \sqrt[10]{\omega''_i} = \sqrt[10]{\prod_{j=1}^{10} a_{ij}}$									
Root of all criteria multi-plications a_{ij} 10th degree	1	3.722	1.625	0.887	2.685	1.692	2.930	0.238	0.380	0.218	0.712
	2	4.487	1.018	0.495	1.061	1.041	1.659	2.352	1.116	0.421	0.218
	3	4.175	2.169	2.169	0.978	0.234	0.360	0.292	0.449	2.169	2.169
	4	3.640	1.414	0.588	1.265	1.473	1.473	0.177	0.298	1.692	1.347
	5	3.942	0.876	0.204	0.279	0.401	2.055	3.075	0.876	1.229	1.863
Step III		ω_1	ω_2	ω_3	ω_4	ω_5	ω_6	ω_7	ω_8	ω_9	ω_{10}
Each element ω'_i is divided by the sum of all elements		$\omega_i = \dfrac{\sqrt[10]{\prod_{j=1}^{10} a_{ij}}}{\sum_{i=1}^{10}\sqrt[10]{\prod_{j=1}^{10} a_{ij}}}$									
All criteria elements nor-malized ω_i values (eigen-vector)	1	0.247	0.108	0.059	0.178	0.112	0.194	0.016	0.025	0.014	0.047
	2	0.324	0.073	0.036	0.076	0.075	0.120	0.170	0.080	0.030	0.016
	3	0.275	0.143	0.143	0.064	0.015	0.024	0.019	0.030	0.143	0.143
	4	0.272	0.106	0.044	0.095	0.110	0.110	0.013	0.022	0.127	0.101
	5	0.266	0.059	0.014	0.019	0.027	0.139	0.208	0.059	0.083	0.126

Table 5. Consistency of the matrix and exerts opinion agreement

Calculation step	Expert	Criteria number									
		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
Step IV		$\lambda'_{max.1}$	$\lambda'_{max.2}$	$\lambda'_{max.3}$	$\lambda'_{max.4}$	$\lambda'_{max.5}$	$\lambda'_{max.6}$	$\lambda'_{max.7}$	$\lambda'_{max.8}$	$\lambda'_{max.9}$	$\lambda'_{max.10}$
Calculated values of the highest eigenvalues λ_{max} components		$\lambda'_{\max,i} = \dfrac{\sum_{j=1}^{10} a_{ij}\omega_j}{\omega_i}$; $\lambda_{\max,i} = \dfrac{\sum_{j=1}^{10}\lambda'_{\max,i}}{10}$									
The element of the column by the respective weight ω_i and the eigenvalue by each expert	1	10.652	10.541	10.585	10.509	10.390	10.565	10.691	10.773	10.746	10.409
	2	10.639	10.322	13.114	10.174	10.974	10.519	10.678	10.226	10.269	10.677
	3	10.901	10.172	10.172	10.497	10.865	11.072	12.044	10.646	10.172	10.172
	4	10.679	10.747	10.435	12.658	10.565	10.565	10.854	10.588	8.186	11.768
	5	10.662	10.592	10.859	10.672	10.679	10.212	10.873	10.288	10.632	10.510
Step V		$S_i = \dfrac{S_I}{S_A} = \dfrac{\frac{\lambda_{\max,i}-m}{m-1}}{1.49} = \dfrac{\frac{\lambda_{\max,i}-10}{10-1}}{1.49}$									
Consistency of the matrix											
The values of a random con-sistency index	*Matrix order*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
	S_A	*0.58*	*0.90*	*1.12*	*1.24*	*1.32*	*1.41*	*1.45*	*1.49*	*1.51*	*1.48*
Consistency		S_1=0.044, S_2=0.057, S_3=0.050, S_4=0.053, S_5=0.045.									
		The value are smaller than 0.1. i.e. the matrix is consistent and experts' estimates are in agreement.									

Table 6. The alternative indicators and triangular fuzzy weights

Criteria	Criteria weight	Alternatives						
		a_1	a_2	a_3	a_4	a_5	a_6	a_7
x_1^*	$\tilde{\omega}_1$	1.50	3.50	0.80	4.80	5.50	0.60	0.30
x_2^*	$\tilde{\omega}_2$	0.60	1.20	0.50	1.20	1.00	0.70	0.40
x_3^*	$\tilde{\omega}_3$	2.50	4.50	3.00	1.60	1.60	2.00	2.00
x_4^*	$\tilde{\omega}_4$	1.37	0.50	0.10	2.00	0.30	0.60	0.60
x_5^*	$\tilde{\omega}_5$	1.25	0.50	0.10	0.50	0.50	0.60	0.50
x_6^*	$\tilde{\omega}_6$	1.31	1.00	2.90	1.50	0.50	0.50	0.50
x_7	$\tilde{\omega}_7$	9.26	8.64	6.44	11.19	5.90	6.09	5.72
x_8^*	$\tilde{\omega}_8$	2.50	1.00	1.00	1.00	1.00	1.20	1.20
x_9	$\tilde{\omega}_9$	3188.6	497.5	2484.0	2676.5	3291.0	6490.0	5946.7
x_{10}	$\tilde{\omega}_{10}$	55269	9327	50798	56206	66807	132136	123314

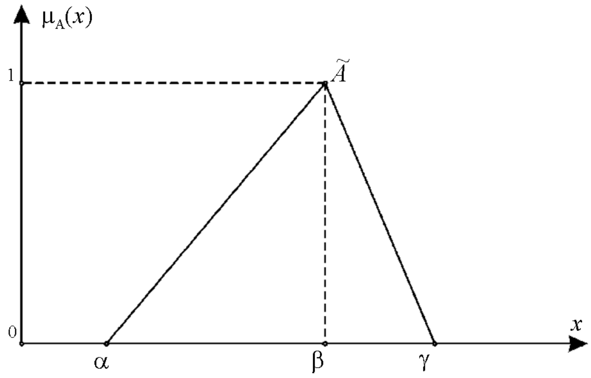

Fig. 3. Triangular membership function

The basic operations of fuzzy triangular numbers $\tilde{n}_1$ and $\tilde{n}_2$ (Laarhoven, Pedrycz 1983; Wang, Elhag 2006; Dursun *et al.* 2011) are defined as follows:

$$\tilde{n}_1 \oplus \tilde{n}_2 = \left(n_{1\alpha} + n_{2\alpha}, n_{1\beta} + n_{2\beta}, n_{1\gamma} + n_{2\gamma}\right) \text{ addition,} \quad (3)$$

$$\tilde{n}_1 (-) \tilde{n}_2 = \left(n_{1\alpha} - n_{2\gamma}, n_{1\beta} - n_{2\beta}, n_{1\gamma} - n_{2\alpha}\right) \text{ subtraction,} \quad (4)$$

$$\tilde{n}_1 \otimes \tilde{n}_2 = \left(n_{1\alpha} \otimes n_{2\alpha}, n_{1\beta} \otimes n_{2\beta}, n_{1\gamma} \otimes n_{2\gamma}\right) \text{ multiplication,} \quad (5)$$

$$\tilde{n}_1 (\div) \tilde{n}_2 = \left(\frac{n_{1\alpha}}{n_{2\gamma}}, \frac{n_{1\beta}}{n_{2\beta}}, \frac{n_{1\gamma}}{n_{2\alpha}}\right) \text{ division,} \quad (6)$$

$$k\tilde{n}_1 = \left(kn_{1\alpha}, kn_{1\beta}, kn_{1\gamma}\right) \text{ multiplication by a constant,} \quad (7)$$

$$\left(\tilde{n}_1\right)^{-1} = \left(\frac{1}{n_{1\gamma}}, \frac{1}{n_{1\beta}}, \frac{1}{n_{1\alpha}}\right). \quad (8)$$

Suppose $\tilde{W} = \left[\overline{\tilde{w}_1, \tilde{w}_n}\right] = \left[\tilde{w}_j\right]$ is a fuzzy group weighted for n criteria and $\tilde{w}_j$ is a fuzzy triangular number:

$$\tilde{w}_j = \left(w_{jl}, w_{jm}, w_{ju}\right), \quad (9)$$

where $w_{j\alpha} = \min\limits_k y_{jk},\ j = \overline{1,n},\ k = \overline{1,p}$ is minimum possible value, $w_{j\beta} = \left(mediana\right)_{jk},\ j = \overline{1,n},\ k = \overline{1,p}$ is the possible value and $w_{j\gamma} = \max\limits_k y_{jk},\ j = \overline{1,n},\ k = \overline{1,p}$. is the maximal possible value of j-th criteria (Turskis, Zavadskas 2010).

The ARAS method was based on the argument that the phenomena of complicated world could be understood by using simple relative comparisons. It is argued that the ratio of the sum of normalized and weighted criteria scores. It describes an alternative under consideration, to the sum of the values of normalized and weighted criteria. These criteria describe the optimal alternative and the degree of optimality, which is reached by the alternative under comparison. (Zavadskas, Turskis 2010).

The ARAS method has a utility function value determining the complex relative efficiency of a reasonable alternative, which is directly proportional to the relative effect of values and weights of the main criteria considered in a project (Zavadskas, Turskis 2010; Tupenaite *et al.* 2010, Zavadskas *et al.* 2010).

The task is resolved using descriptions of alternating factors specified in Table 6 and calculated significance of the above factors stated in Table 4.

The criteria, whose preferable values are maximum, are normalized as follows:

$$\tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}}. \quad (10)$$

The criteria, whose preferable values are minimal, are normalized by applying the following two-stage procedure:

$$\tilde{x}_{ij} = \frac{1}{\tilde{x}_{ij}^*}; \quad \tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}}. \quad (11)$$

Table 7. The changed fuzzy decision making matrix with fuzzy criteria weights

Criteria	Criteria weight			Alternatives							
				a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
x_1	$\tilde{\omega}_1$	$\omega_{\alpha.1}$	0.247	3.33	0.67	0.29	1.25	0.21	0.18	1.67	3.33
		$\omega_{\beta.1}$	0.272								
		$\omega_{\gamma.1}$	0.324								
x_2	$\tilde{\omega}_2$	$\omega_{\alpha.2}$	0.059	2.50	1.67	0.83	2.00	0.83	1.00	1.43	2.50
		$\omega_{\beta.2}$	0.106								
		$\omega_{\gamma.2}$	0.143								
x_3	$\tilde{\omega}_3$	$\omega_{\alpha.3}$	0.014	0.63	0.40	0.22	0.33	0.63	0.63	0.50	0.50
		$\omega_{\beta.3}$	0.044								
		$\omega_{\gamma.3}$	0.143								
x_4	$\tilde{\omega}_4$	$\omega_{\alpha.4}$	0.019	10.00	0.73	2.00	10.00	0.50	3.33	1.67	1.67
		$\omega_{\beta.4}$	0.076								
		$\omega_{\gamma.4}$	0.178								
x_5	$\tilde{\omega}_5$	$\omega_{\alpha.5}$	0.015	10.00	0.80	2.00	10.00	2.00	2.00	1.67	2.00
		$\omega_{\beta.5}$	0.075								
		$\omega_{\gamma.5}$	0.112								
x_6	$\tilde{\omega}_6$	$\omega_{\alpha.6}$	0.024	2.00	0.76	1.00	0.34	0.67	2.00	2.00	2.00
		$\omega_{\beta.6}$	0.120								
		$\omega_{\gamma.6}$	0.194								
x_7	$\tilde{\omega}_7$	$\omega_{\alpha.7}$	0.013	11.19	9.26	8.64	6.44	11.19	5.90	6.09	5.72
		$\omega_{\beta.7}$	0.019								
		$\omega_{\gamma.7}$	0.208								
x_8	$\tilde{\omega}_8$	$\omega_{\alpha.8}$	0.022	1.00	0.40	1.00	1.00	1.00	1.00	0.83	0.83
		$\omega_{\beta.8}$	0.030								
		$\omega_{\gamma.8}$	0.080								
x_9	$\tilde{\omega}_9$	$\omega_{\alpha.9}$	0.014	6490	3189	497	2484	2676	3291	6490	5947
		$\omega_{\beta.9}$	0.083								
		$\omega_{\gamma.9}$	0.143								
x_{10}	$\tilde{\omega}_{10}$	$\omega_{\alpha.10}$	0.016	132139	55269	9327	50798	56205	66807	132136	123314
		$\omega_{\beta.10}$	0.101								
		$\omega_{\gamma.10}$	0.143								

When the dimensionless values of the criteria are known, all the criteria, originally having different dimensions. The criteria with different dimensions can be compared (Table 7).

Normalized-weighted values of all the criteria are calculated as follows:

$$\tilde{\hat{x}}_{ij} = \tilde{\bar{x}}_{ij}\tilde{w}_j; \qquad i = \overline{0, m}, \tag{12}$$

where w_j is the weight (importance) of the j criterion and $\bar{x}_{ij}$ is the normalized rating of the j criterion.

The following task is determining values of optimality function:

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{\hat{x}}_{ij}; \qquad i = \overline{0, m}, \tag{13}$$

where $\tilde{S}_i$ is the value of optimality function of i-th alternative. The biggest value is the best, and the least one is the worst. Taking into account the calculation process, the optimality function $\tilde{S}_i$ (Table 8) has a direct and proportional relationship with the values x_{ij} and weights $\tilde{\omega}_j$ of the investigated criteria and their relative influence on the final result. Therefore, the greater the value of the optimality function $\tilde{S}_i$, the more effective the alternative. The priorities of alternatives can be determined according to the value S_i. Consequently, it is convenient to evaluate and rank decision alternatives when this method is used (Turskis, Zavadskas 2010).

According to the solution, it could be stated that alternatives are as follow:

$$a_4 \succ a_5 \succ a_2 \succ a_1 \succ a_3 \succ a_6 \succ a_7.$$

Three localized areas as the most rational places suitable for construction of the waste incineration plant within the territory o the city are named during the assessment of the alternatives. Two areas of the territory designated for industrial urban development are formed (a_4, a_1 and a_2, a_3, a_5) and one area in a densely populated urban district (a_6, a_7).

Analysing principles of the sustainable development irrespectively of the calculation results, a_6 and a_7 alternatives are not considered to be appropriate for development of industrial facilities such as waste incineration plants. Development of such type of facilities within the mentioned area will damage the social life of residents. Rehabilitation centre for children and adults, banks of River Neris and the majority of health care institutions of Vilnius Region are located in the adjacent territory. Besides, dense population of the above mentioned territory can cause strong opposition of citizens to the construction

Table 8. Solution results

		Alternatives							
		a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
Fuzzy weights	$\tilde{S}_{\alpha i} = \sum_{j=1}^{10}\left(\left(\frac{x_{ij}}{\sum_{j=1}^{10} x_{ij}}\right)\cdot \omega_{\alpha,j}\right)$	0.117	0.063	0.109	0.045	0.133	0.144	0.037	0.028
	$\tilde{S}_{\beta i} = \sum_{j=1}^{10}\left(\left(\frac{x_{ij}}{\sum_{j=1}^{10} x_{ij}}\right)\cdot \omega_{\beta,j}\right)$	0.230	0.123	0.172	0.112	0.195	0.197	0.098	0.085
	$\tilde{S}_{\gamma i} = \sum_{j=1}^{10}\left(\left(\frac{x_{ij}}{\sum_{j=1}^{10} x_{ij}}\right)\cdot \omega_{\gamma,j}\right)$	0.390	0.267	0.352	0.250	0.329	0.307	0.208	0.190
Value of optimality function *i*-th alternative	$S_i = \frac{1}{3}(S_{i\alpha} + S_{i\beta} + S_{i\gamma}).$	0.245	0.151	0.211	0.136	0.219	0.216	0.114	0.101
Utility degree	$K_i = \frac{S_i}{S_0};$	*1.000*	*0.614*	*0.859*	*0.552*	*0.891*	*0.880*	*0.466*	*0.412*

of waste handling and incineration plant within their residential environment.

The area, including a_2, a_3 and a_5 alternatives, raises problems related to connection of engineering communications and building of required roads. The main problem of the above area arising during the design of the incineration product stack of the waste incineration plant is the Vilnius airport. Consequently, from the point of view of sustainable development, all requirements of concerned citizens will be fulfilled if a_4 or a_1 alternatives determined in accordance with calculation results are selected for construction of the waste incineration plant.

Problem solving is performed on the basis of evaluation of citizens, potential investors, specialists of environmental protection, architects and construction contractors, proving the interrelation between calculation results and logical description of disadvantages of the alternatives.

Application of the AHP and the ARAS-F combination revealed that the most suitable site for the waste incineration plant is the alternative a_4. This site is located in Paneriai industrial region, which is alienated from densely populated urban districts. The most unsuitable place is alternative a_7 (territory near the 8th regional boiler house). This densely populated area designated for recreation cannot be used for construction of the waste incineration plant.

6. Conclusions

Siting of the waste incineration plant is a complex process which includes social, economic, political and technologic factors. Project implementation engages different concerned social groups, interest of which shall be confined, in order to ensure the success of the project. Consequently, the most rational solutions can be delivered by applying scientific methods comprising and evaluating the large volume of information.

Complex AHP and ARAS-F methods were used to find a solution, in order to determine the most convenient alternative. Significance of expert estimations were assessed with the help of the AHP method. The ARAS-F method was applied for determination of the most convenient alternative.

Seven alternative sites for construction of the waste incineration plant in Vilnius city were evaluated. The alternatives are distributed within densely populated urban and industrial development areas. The multiple criteria task was defined in order to determine the appropriate alternative.

According to the calculated results, it was observed that the most convenient place for construction of non-hazardous waste incineration plant in Vilnius city is located in Paneriai industrial region (Fig. 1, No 4). As During assessment of possible alternatives for construction of the waste incineration plant, the northern part of Vilnius city (Fig. 1, No 7) was found to be the most unsuitable area.

In order to perform precise assessment of stakeholder positions and determine the objective opinion concerning the implementation of the waste incineration plant project, different opinions of experts related to the issue will be evaluated. During the assessment of all alternatives, it will be rational to use project implementation costs for calculation, their return and behaviour of produced electricity prices on the local market.

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STATYBVIETĖS PARINKIMO NEPAVOJINGŲ ATLIEKŲ DEGINIMO ĮMONEI VILNIUJE VARIANTŲ VERTINIMAS *AHP* IR *ARAS-F* METODAIS

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Santrauka

Nuolat didėjančios gyventojų vartojamos elektros ir šilumos energijos kainos verčia ieškoti alternatyvių sprendimų racionaliau naudoti turimus išteklius – mažinti energijos gamybos išlaidas. Nagrinėjama statybvietės būsimai atliekų deginimo įmonei parinkimo problema. Jos sprendimas susijęs su investuotojų, gyventojų, rangovų ir kitų suinteresuotųjų grupių poreikiais. Parenkant vietą siekiama atsižvelgti į šių grupių pageidavimus, todėl formuluojamas daugiakriteris uždavinys. Vertinamos septynios tam parinktų vietų miesto pramonės plėtros ir tankiai gyvenamose teritorijose alternatyvos. Skaičiavimų rezultatai rodo, kad tokio tipo pramonės objektų kūrimas susijęs su ekonominiais, socialiniais ir aplinkosaugos veiksniais. Nustatyta, kad tinkamiausia vieta atliekų deginimo įmonei statyti yra Panerių pramoninis rajonas. Netinkamiausia atliekoms deginti vieta yra tankiai apgyventi miesto mikrorajonai. Geriausio rezultato paieškai taikomas kompleksinis sprendimas *AHP* ir *ARAS-F* metodais.

Reikšminiai žodžiai: atliekų deginimas, alternatyvioji energija, *AHP* ir *ARAS-F* metodai, statybvietės parinkimas, atliekų tvarkymo technologijos.

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