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METHODOLOGY BASED ON FUZZY SET THEORY WHEN WASTE HAS SIMILAR CHAPTER' DESCRIPTIONS IN THE LIST OF WASTE

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Abstract

The aim of this paper is to propose a methodological approach (principle, theory, algorithm) to decide about the most appropriate waste code to be assigned to a waste, when similar descriptions can be given to it under more than one chapter of the harmonized list of waste, considering the total amount of available information (data, evidences and knowledge). Based on the extension principle of fuzzy set theory, the methodological approach is meant to help any waste evaluator of producer/holder organization to have a scientifically sound based decision about the best code to be assigned to the waste in those particular situations The correct waste classification is the basis for their further adequate management in order to prevent both consumption of non-renewable or hard renewable raw materials and the pollution risk for the environment and human health supporting this way the implementation of waste hierarchy principle for economic sustainability.

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1. Introduction

Waste classification according to the European law (EC Decision, 2000; EC Directive, 2008; EC Regulation, 2006, 2008, 2014) means to assign *a six-digits numerical code* from the harmonized LoW (English acronym for List of Waste) applying a prescribed classification procedure based on information about waste generation source (industry/process/type of waste).

In the LoW, waste is described and classified under 20 chapters (two-digits codes), further divided into sub-chapters (four-digits codes) and entries (six-digits codes). The assignment of a specific entry is made by following a procedure that creates an order of precedence for chapters, namely first should be examined chapters from 01 to 12 and 17 to 20 - their titles making reference mainly to the waste generating industry and process -, then chapters 13-15 - their titles making reference to the type of waste - and finally, chapter 16 its title being dedicated to '*wastes not otherwise specified in the LoW*'. First, we search and find the best fit with the scope defined under the chapter title and sub-chapter titles. Finally, a corresponding entry should be found for the best-found chapter and sub-chapter. The recommendation is that the entry with six-digits should give a complete description of the waste to the best of available information, avoiding as much as possible the 99 final two-digits entries reserved for waste not otherwise specified. An entry with 99 final two-digits should be the last option for a waste classification. With reference to the assignment of an adequate entry under the best fit for the found chapter and sub-chapter we should mention that any waste that in the LoW can be identified by an entry marked with an asterisk (*) is considered as hazardous. Wastes defined by all other entries are considered as non-hazardous. According to the harmonized LoW and procedure (EC Decision, 2000) wastes which are assigned to an entry with asterisk are named AH entries (English acronym for Absolute Hazardous). The AH entries are hazardous without any further assessment. Waste which are assigned to an entry without asterisk are named ANH entries (English acronym of Absolute Non-Hazardous). The ANH entries are non-hazardous without any further assessment. The AH entries cannot be allocated to non-hazardous entries and the same is true for ANH entries that cannot be allocated to hazardous one.

In the LoW there are also mirror entries defined as two or more related entries where one is hazardous and is named MH (English acronym for Mirror Hazardous) and the other is non-hazardous and is named MNH (English acronym for Mirror Non-Hazardous). In contrast to AH or ANH entries, if waste is to be allocated to a group of alternative entries, further steps in the assessment for allocation have to be undertaken All the time, relevant data should be gathered in order to assign an entry that completely characterizes the waste to the best of existing information about it. Recommendations EC Notice C124/01 (EC Notice, 2018) show that *'there are several ways to gather information on relevant composition of the waste, the present hazardous substances and potential hazardous properties displayed and they are directed towards information related to detailed 'waste' generating manufacturing process/chemistry and its input substances and intermediates'*. This information may include also expert judgments and as useful sources are recommended BREF reports, industrial process handbooks, process descriptions and lists of input materials provided by the producer. Also, useful information might be gathered from: the original producer of the substances or objects before they became waste, e.g. Safety Data Sheets (SDS), product label or product fiches, available databases on waste analyses, sampling and chemical analysis of the waste. Once the information on waste composition has been collected, it becomes possible to assess if the identified substances are classified as hazardous, i.e. if they are assigned a hazard statement code. According to CLP Regulation - English acronym for Classification, Labeling and Packaging of substances and mixtures (EC Regulation, 2008) a *'hazard statement'* means a phrase assigned to a hazard class and category that describes the nature of the hazards of a hazardous substance or mixture, including, where appropriate, the degree of hazard. Recommendations EC Notice C124/01 (EC Notice, 2018) mention *'that although direct testing methods are available for some hazardous properties, they are not available for all hazardous properties. As a consequence, direct testing cannot be used to fully classify a waste of unknown composition as non-hazardous'*.

The process of classification implies assessment of available information from a variety of fields and it is not a trivial work. If sometimes the organization evaluator can assign without difficulties AH or ANH codes based on available information, when mirror entries are involved, the process of classification is complex and usually expert evaluators are needed. The preoccupations of our society about correct waste classification and management starting with regulatory organizations, practitioners and academics and finishing with non-governmental groups and general public are becoming greater and greater in the face of climate changes. Analytic determinations of those hazardous properties are of great importance to help complete the relevant information to the classification when hazardous properties might be imparted to the wastes by hazardous contained substances exceeding certain legally stated thresholds limits (Kim et al., 2017, 2018b; Serbanescu et al., 2018). In each classification process information about environmental and human health impact and risk evaluations are also needed in order to assess how well the principles of waste hierarchy, sustainable development and circular economy will be applied in the view of further waste management process. Multicriterial decision methods are among most reliable and actually the most used in environmental impact and risk assessments. Our preoccupations in last decades have been concentrated on those types of methods because they are able to structure the multitude of information needed (Arama, 2007a, 2007b; Arama and Kim, 2016; Arama and Nicolau, 2009a, 2009b, 2009c; Arama et al., 2010a, 2010b, 2010c, 2011, 2013, 2015, 2017a, 2017b, 2018a, 2018b; Comăniţa et al., 2018; Gheorghe et al., 2010; Guta et al., 2014, 2017; Kim and Arama, 2018; Kim et al., 2018a).

So, the adequate code assignment is an essential step in the waste management process for correct waste labeling in order to be adequately stored, transported, treated for valorization or finally disposed. However, there are situations when based on available information, a waste under classification can be given similar descriptions under more than one chapter. For those specific situations EC Notice C124/01 (EC Notice, 2018) recommends: *'instead of considering the general type of industry where the waste arises, one should rather consider the specific industrial process'*. One example is waste from the automotive industry: depending on the process, waste can be classified in: '*chapter 08 (wastes from the manufacture, formulation, supply and use (MFSU) of coatings* (*paints, varnishes and vitreous enamels), adhesives, sealants and printing inks*), *chapter 11* (*wastes from chemical surface treatment and coating of metals and other materials; non-ferrous hydro-metallurgy*) or *chapter 12* (*wastes from shaping and physical and mechanical surface treatment of metals and plastic*)'. This recommendation directs to the fact that information giving under sub-chapters can be used to support the classification under a given chapter. In this specific case giving as example, the automotive industry cannot be found in clear in any chapter title scope from the LoW. Considering all the available information, a waste producer from this industry can find its waste described in similarly manner under few chapters (chapters 08, 11 and 12). However, this is a situation when the waste producer should decide which chapter title scope gives the best description of the waste under consideration. We propose a fuzzy methodology to be followed in order to motivate organization final decision based on extension principle of fuzzy theory first introduced by Zadeh that will be summarized below for this specific proposed application.

2. Material and methods

'*Fuzzy set theory provides a strict mathematical framework to generalizes the classical notion of set and proposition to accommodate fuzziness in the sense that is contained in human language, judgement, evaluations and decisions (…) extending the 'dual/classical' logic that asserts that a statement can be either true or false and nothing in between, to real life situations*' (Zadeh cited in Zimmerman, 2010). As Zadeh stated it is specifically useful '*when dealing with problems in which there is imprecision arising from the absence of 'sharply' defined criteria of class membership*' (Zadeh cited in Zimmerman, 2010; Zadeh, 1975a, 1975b), as is almost all the time the case where those criteria are formulated in natural language. It is extensively used in a lot of fields but especially in AI (English Acronym for Artificial Intelligence), robotics, fuzzy control etc. (Lee, 2005). Fuzzy set theory provides a framework for thinking and modelling the information processing. Modelling the waste classification process, considering the amount of available information about it might be another useful application, in order to decide the best code to be assigned to that waste, when similar linguistic descriptions can be given under more than one *chapters* of LoW.

The basics of theory, principle and algorithm for such methodology is presented next. So, the concept of fuzzy sets has been introduced for situations when the binary logic of all or nothing type - the assertion can be either truth or false - is less or not applicable. In logic, the aggregated of all objects, attributes, and relations assumed or implied in a given discussion about a certain topic is called universe of discourse. In mathematics the universe of discourse is the set of all elements under discussion for a given problem and it is also called universal set. If we define a set A in the universal set, we have the following valid relation ~~A~~ $A \subseteq X$. If we use the membership function (characteristic function or description function) we can see if an element x is in the set A or not. For a set A we define membership function $\mu_A(x) = 1$, if and only if $x \in X$ and $(x) = 0$ if and only if $x \notin X$.

We can say that function $\mu_A(x)$ maps the elements in universal set X to the set {0, 1} (Eq. 1).

$$\mu_A(x): X \to \{0,1\} \tag{1}$$

A power set *P(A)* is a set containing all subsets of A and its cardinality (number of comprised sets) is important in the present fuzzy set context when relationships of different types are described on it (Eq. 2):

$$|P(A)| = 2^{|A|} \tag{2}$$

Fuzzy set can be introduced as an extension of crisp set with reference to characteristic (membership) function as shown next. Membership function $\mu_A(x)$in a crisp set, maps members in universal set *X* to the set {0,1} assuming that they are either member of the set or not. In a fuzzy set each element is mapped to the number in the interval [0,1] with reference to its membership function.

Let be the two set X and Y crisp/classical defined sets and *f* a map (function) so that *f: X→Y*. In a mapping provided by the general function *f: y =f(x)* if the input x is crisp, then the resulting output *y* is also crisp. An extension principle developed by Zadeh (Zadeh, 2008) enables the extension of *the domain of a function* on *fuzzy sets*. Literature in the field Lee (2005), Zimmerman (2010) shows that it generalizes a common *point to point mapping function* f (.) to *a mapping between fuzzy sets*. Let A, B be two fuzzy sets defined in the universe of discourse X respective Y. Let R denotes a relation from A to B. Thus, relation can be expressed by a function f where $x \in A, y \in B, y = f(x)$ or $x = f^{-1}(y)$. The literature mentions that here one uses the term function without considering the strict word for being a mathematical function and then one can obtain a fuzzy set B' in B by R and A for $y \in B$ (Eq. 4)(Lee, 2005; Zadeh, 2008; Zimmerman, 2010).

$$\mu_{B'}(y) = \begin{cases} \underset{x \in f^{-1}(y)}{Max} [\mu_A(x)], \text{if } f^{-1}(y) \neq \emptyset \\ 0, if\ f^{-1}(y) = \emptyset \end{cases} \tag{3}$$

R might be a function (a map) or any other relation that is not a function e.g. a 'one to many' type relation. In our application the relation is of 'many to one' type as we formulated the sets. In many branches of mathematics, the term map is used to mean a function sometimes with a specific property of particular importance to that branch.

3. Case study

According to the above-mentioned extended principal the following generic algorithm can be shown for the proposed application.

Let be **X** the (crisp) set of '*type of information requirements according to European legal harmonized classification procedure to classify waste'*. The elements of **X** $=\{x_1, x_2, x_3, x_4\}$ represent explicitly: x_1 =information about waste generation industry/industrial sector, x_2 =information about waste generation industrial process, x_3=information about the waste type, x_4 =information about physical/chemical/biological characteristics of the generated waste. Let it be:

- Y the (crisp) set of '*chapters giving descriptions of wastes under their titles from LoW';*

- A the (fuzzy) set of '*how well each type* of *existing, available information supports descriptions under chapter titles from LoW* ';

- B the (crisp) **s**et of '*chapters from LoW giving similar descriptions for the waste under* *classification considering, existing, available information';*

- B' the (fuzzy) set of *'how well existing, available information total supports each chapter giving similar descriptions under chapter titles from the LoW'.*

Considering the above-mentioned case from the automotive industry we do the following remarks. Available data about the waste under classification are usually given as linguistic technical descriptions and also numerical analytical data and it should be synthetized with relevance in order to transform it in information. Suppose that the organization has also evidences and knowledge about qualitative and quantitative variations in the composition of produced waste depending on the specificity of their production (items and quantities). However, those variations remain in certain range of acceptability (tolerance) from the point of view of the waste composition. Taking into account the imprecise available information – imprecision mostly '*due not to the lack of information* but *to the nature of available information'* to be matched to the concepts expressed by the title of each chapter regarding the scope of chapter applicability – suppose that the organization evaluator, although synthetized and structured the available information as recommended under the legal procedure, he/she still found three possible similar descriptions for the generated waste under classification.

To decide which is the best match/fit for the waste and to document the made choice we propose the following algorithm. Suppose that each type of information can be characterized by the evaluator as follows from the point of view of how well can support the found similar descriptions:

- low support when the degree of support is between (0.1 …0.3];
- medium support when the degree of support is between (0.3… 0.6];
- high support when the degree of support is between (0.6… 0.9].

Suppose that taking into consideration each type of available information the evaluator can construct the following fuzzy set A = {(x_1, 0.6), (x_2, 0.3), (x_3, 0.2), (x_4, 0.1)} with membership functions expressed besides each type of required information.

According to the definitions of extension principle we can write:

1) For the chapter 08 - wastes from the manufacture, formulation, supply and use (MFSU) of coatings (paints, varnishes and vitreous enamels), adhesives, sealants and printing inks (Eq. 4):

$$f^{-1}(y_1) = [(x_1, 0.6), (x_3, 0.2)] \rightarrow Max[0.6, 0.2] = 0.6 \rightarrow \mu_{B'}(y_1) = 0.6 \quad (4)$$

2) For the chapter 11 - wastes from chemical surface treatment and coating of metals and other materials; non-ferrous hydro-metallurgy (Eq. 5)

$$f^{-1}(y_2) = [(x_4, 0.1)] \rightarrow Max[0.1] = 0.1 \rightarrow \mu_{B'}(y_2) = 0.1. \quad (5)$$

3) For the chapter 12 - wastes from shaping and physical and mechanical surface treatment of metals and plastic (Eq. 6-7):

$$f^{-1}(y_3) = [(x_2, 0.3)] \rightarrow Max[0.3] = 0 \rightarrow \mu_{B'}(y_3) = 0.3 \quad (6)$$

$$B' = \{(y_1, 0.6), (y_2, 0.1), (y_3, 0.3)\} \quad (7)$$

'*Max*' operation under the fuzzy set theory (extension principle) is the operation that has the significance of union operation under corresponding crisp set theory (Balakumar and Soundharya, 2018). Membership of fuzzy set B' showing how much each title with similar descriptions is supported by all the useful information of required type reveals that the greatest membership is 0.6 corresponding to the chapter 08, the second is chapter12 and third is chapter 11 (Fig. 1).

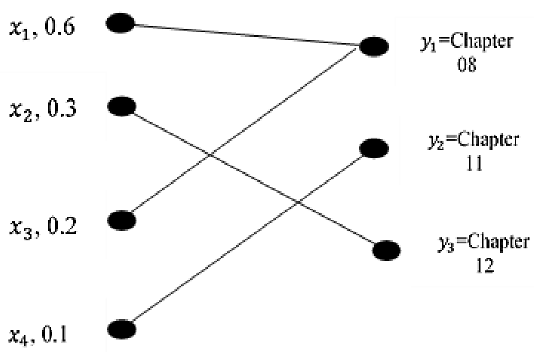

Fig. 1. Extension principle - Relation between set A and B illustrating the construction of the fuzzy set B'⊆ B

With presented algorithm the organization evaluator can document why they have chosen chapter 08 from the three chapters with similar descriptions. The example is generic. The proposed methodology tries to adjust the great amount of different information and to make it available in a structured way for decision. The evaluator job is to judge and balance the quality and the quantity of total available *relevant*, *useful information* that can give the closest possible descriptions to the scope of one chapter. However, when different type of required information sustains an approximate well fit to more than one chapter title defining the scope applicability, to reach a decision for a best fit, the proposed algorithm could be applied and the proposed methodology has the following sequence of actions.

1. Gather and synthetize information about waste source - waste generating industry/industrial sector/process/type along with other information about qualitative/quantitative information about contained substances and specific waste characteristics.

2. Follow the legal search procedure in the set order of precedence of chapters to find a best fit for the waste under classification with the scope of one chapter title and then follow the same procedure for sub-chapter and entry under the corresponding found chapter.

3) If found similar possible descriptions under more than one *chapter*, apply the following further steps:

3a. - Assign membership degrees for the elements of set A appreciating based on available existing information '*how well each type* of *existing, available information supports descriptions under chapter titles*' from the following linguistic scale.

- low support when the degree of support is between (0.1 …0.3];

- medium support when the degree of support is between (0.3… 0,6];

- high support when the degree of support is between (0,6… 0.9];

3b. - Make a graph as in Fig. 1 showing the relations between information of each type that can be used under similar found descriptions emphasizing this way the contribution of total available useful information to each similar description under each chapter.

3c. - Apply the max operation and find the membership degree of set B' showing *how well total useful available information* supports classification under each chapter. The greatest membership is for the chapter whose title scope description is best supported by *total existing information in the view of the evaluator.*

4. Document this way the chosen chapter.

The proposed methodology can help a waste producer/evaluator to obey the harmonized legal procedure and to make a best fit with the scope of one single chapter that is best supported by the existing information. This methodology had the purpose to offer an instrument to reassess/reconsider a classification done at a certain moment by a certain waste producer/evaluator having certain data (proves) and information (evidences) for a waste of this category. People making a classification with this methodology considering the current legal documents and the guidance for applying them should understand better how to address what happens when available data and information for classification purpose are not quite clear and we believe that this methodology offers a procedural instrument to address the epistemic uncertainty. The given example in the paper is a generic one from automotive industry and is also supported by the present EC Notice (2018). It shows that can be difficult to classify such a waste due to similar descriptions from different chapters but it doesn't show how can be made such correct classification according to the available data and information. The classification can consider: chapter 08 (wastes from the manufacture, formulation, supply and use (MFSU) of coatings (paints, varnishes and vitreous enamels), adhesives, sealants and printing inks): chapter 11 (wastes from chemical surface treatment and coating of metals and other materials; non-ferrous hydro-metallurgy) or chapter 12 (wastes from shaping and physical and mechanical surface treatment of metals and plastic). The available data and information about the waste in this case might be a compilation that can fit in different chapters because the boundaries of phrase the *'waste from'* used to define *'the concept of waste origin'* are not sharply defined which is actually a specificity of the classification process of such magnitude that is trying to cover a large variety of existing or possible existing wastes. They are very general, and they are referring to waste from the use of coatings during different coating processes on metallic or plastic materials that can support different physical and chemical treatments. So, such data and information in this case can fit either: 1) under chapter 08 *'waste from in use of coatings (specified as paints, varnishes and vitreous enamels)'*, or 2) under chapter 11 waste from chemical surface treatment and coating of metals or other materials that are coming also *'from the coating processes on metals and any other type of material'* or 3) under chapter 12 wastes from shaping and physical surface treatments of metals and plastic that are coming as well as *'from the coating processes such are treatments of surface for coatings'*. All three chapters are *'waste from'* uses of coatings which is similar actually with *'coatings processes'*. With reference to the gathered proves and evidences, some of them can be more or less informative on the topic of classification waste from coatings process. It can happen that one evaluator *'believes'* that some available data (proves) and information (evidences) define and cover better in his/her own *'value judgments system'* the topic of coating process applicable to the wastes under consideration than data (proves) and information (evidences) gathered by another evaluator on the '*same type*' of target waste under consideration. Those proves and evidences brought by the two evaluators might be of course different but they are used to assess the same or slightly different *'type'* of waste targets with the same kind of method and *'type'* of criteria (i.e. match with title chapters, subchapters, code in a certain priority order)! If the waste is of the same origin i.e. is *'coming from'* - phrase that is semantically similar with the phrase *'waste from'* - we might expect to have the same code!

This is the type of epistemic uncertainty that can arise in practice. It can be addressed in a fuzzy settings approach! It can explain how the same semantic value describing *'the waste coming from a coating process'* can be assigned to two different classes (chapters) when using similar descriptions (terms, concepts etc.) without a detailed semantic boundaries or otherwise saying with no '*sharply*' defined criteria of class membership. Expert evaluation can bring more clarity to the classification depending to the degree of knowledge they have for ~~to~~ the specific classification process. They can help to assess within the proposed methodology how much from the available data (proves) and information (evidences) can rational-critical-argumentative support a classification under a chapter or another. This type of classification can be submitted to a second opinion. It is a judgmental assessment, not easy, not trivial and the proposed methodology can be used to address such *'semantic similar'* and yet technical *'different'* descriptions. The use of fuzzy set theory has proven to be useful instruments in many such applications such as categorial data classification also in sensitive areas such as environmental and health risk assessment, medicine, epidemiology etc. (De Barros et al., 2003, Plerou et al., 2016; Yang et al., 2008).

4. Conclusions

The presented methodology should be considered as a helpful instrument to document the decisions when a great deal of information about the waste under classification although structured can lead to similar waste descriptions under more than one chapter from the list of waste.

As finally the evaluator should reach to choose a single best fit description, the proposed methodology can give a scientifically sound motivation for the chosen chapter and will be a helpful decision instrument.

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References

Arama G.M., (2007a), *Evidential Reasoning Approach – A Reliable Instrument in Multiple Attribute Decision Making Process Under Uncertainties*, Int. Symp. The Environment and Industry, Bucharest, vol. II, 353-358.

Arama G.M., (2007b), *Environmental Risk Minimization by Adequate Alternative Selection from a Set of Available Alternatives Using Evidential Reasoning Approach*, Int. Symp. The Environment and Industry, Bucharest, vol. II, 337-341.

Arama M., Nicolau M., (2009a), *Epistemic and Measurement Uncertainty in Environmental Impact/Risk Assessments*, Int. Symp. The Environment and Industry, Bucharest, vol. II, 72-80.

Arama M., Nicolau M., (2009b), *Rough Set Theory - Decision Support Instrument in the Environmental Risk Management of Water Bodies in Romania*, Int. Symp. The environment and Industry, Bucharest, vol. II, 80-87.

Arama M., Nicolau M., (2009c), *Water Body Impact and Risk Assessment Methodology*, Int. Symp. The Environment and Industry, Bucharest, vol. II, 87-93.

Arama M., Gheorghe V.A., Radu C., Stanciu R.D, Nicolau M., (2010a), Basic concepts and pollution a causal chain in environmental risk assessment, *Revista de Management si Inginerie Economica*, **9**, 37-46.

Arama G.M., Gheorghe V.A., Radu C., Stanciu R.D., Nicolau M., (2010b), Ecological risk assessment methodology based on evidential reasoning algorithm, *UPB Scientific Bulletin, Series D*, **72**, 181-194.

Arama G.M., Gheorghe V.A., Radu C., Stanciu R.D., Nicolau M., (2010c), Advantages of new ecological impact/risk assessments, *UPB Scientific Bulletin, Series D*, **72**, 213-222.

Arama M., Stanciu R., Nicolau M., (2011), *Assessing and Managing the Water Quality Risk – A Way to Attend Sustainability*, 2nd Review of Management and Economic Engineering Management Conference (RMEE), Technical University of Cluj Napoca, Romania, 8-13.

Arama G.M., Anghel A., Criste V., (2013), EMAS III relevant indicators to measure EMS performance, *Metalurgia International*, **18**, 111-114.

Arama G.M., Pascu L.F., Guta D., (2015), *Decision Model Based on Analytical Hierarchy Process for Managing the Environmental Risks Within the Environmental Management Systems*, Int. Symp. The Environment and Industry, National Research and Development Institute for Industrial Ecology, Bucharest, 118-123.

Arama G.M., Kim L., (2016), *Using Waste Hierarchy Concept for Optimizing the Management of the Waste Disposal Amount and Implicitly of the Possible Ecological Risk*, Int. Symp. The Environmental and The Industry, National Research and Development Institute for Industrial Ecology, Bucharest, 66-72.

Arama G.M., Pascu L.F., Lehr C., (2017a), Prediction of the concentration of pollutants wave in aquatic environment using rough set theory, *Environmental Engineering and Management Journal*, **16**, 1217-1225.

Arama G.M., Kim L., Guta D., (2017b), *General Scheme to Evaluate the Dangerousness of Waste in Order to Manage Them by Producer/Holder Organization*, 20th Int. Symp. The Environmental and The Industry (SIMI 2017), National Research and Development Institute for Industrial Ecology, Bucharest, 151-158.

Arama G.M., Pascu L.F., Lehr C., (2018a), Selection and use of EMAS III indicators and AHP methodology in analysis of organization environmental performance, *Environmental Engineering and Management Journal*, **17**, 1217-1227.

Arama G.M., Kim L., Cuciureanu A., Serbanescu A., Nicolescu I., Barbu M., Stanescu B., Traistaru G., (2018b), *End of Waste Criteria for Oil Wastes*, 21st Int. Symp. The environment and the Industry, Bucharest, 1843-5831.

Balakumar R., Soundharya M., (2018), Fuzzy arithmetic and extension principle, *International Journal on future Revolution in Computer Science and Communication Engineering*, **4**, 54, Online at: http://www.ijfrcsce.org.

Comăniţa E.D., Cozma P., Simion I.M., Rosca M., Gavrilescu M., (2018), Evaluation of eco-efficiency by multicriteria decision analysis, case study of eco-innovated and eco-designed products from recyclable waste, *Environmental Engineering and Management Journal*, **17**, 1791-1804.

EC Decision, (2000), Commission Decision 2000/532/EC of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1 (4) of Council Directive 91/689/EEC on hazardous waste, Official Journal of European Communities, L226, 06.09.2000, Brussels.

De Barros L.C., Ferreira Leite M.B., Bassanezi R.C., (2003), The SI epidemiological models with a fuzzy transmission parameters, *Computers and Mathematics with applications*, **45**, 1619-1628.

EC Directive, (2008), Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, *Official Journal of European Communities*, L312, 22.11.2008, Brussels.

EC Regulation, (2006), Regulation No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC, *Official Journal of European Communities*, L396, 30.12.2006, Brussels.

EC Regulation, (2008), Regulation no. 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labeling and packaging of substances and mixtures, amending and repealing Directive 67/548/EEC and 1999/45/EC and amending Regulation (EC) no. 1907/2006, *Official Journal of European Communities*, L353, 31.12.2008, Brussels.

EC Regulation, (2014), Regulation no 1357/2014 of 18 December 2014 replacing Annex III to Directive 2008/98/EC of the European Parliament and of the Council on waste and repealing certain Directives, *Official Journal of European Communities*, L365, 19.12.2014, Brussels.

EC Notice, (2018), Commission notice on technical guidance on the classification of waste (2018/C 124/01), *Official Journal of European Communities*, C 124, Volume 61, April 9 2018, Brussels.

Gheorghe V.A., Aramă G.M., Radu C., Stanciu R.D., Nicolau M., (2010), Ecological risk assessment methodology based on evidential reasoning algorithm, *UPB Scientific Bulletin*, Series D, **72**, 181-194.

Guta D., Arama G.M., Stanescu B., Batranescu Gh., Lehr C.B., (2014), *Hazard Assessment for Wastes Using Multicriterial Methods Considering European and International Harmonized Legislation*, Conf. Proc. of Int. Congress on "Green Infrastructure and Sustainable Societies/Cities 'GreInsu'14s, Izmir, Turkey, 2014, 82-86.

Guta D., Cuciureanu A., Kim L., Arama M., (2017), *The Assessment of Dangerousness Waste. Case Study: Waste Originating From Drilling Muds*, Proc. 20th Int. Symp. The Environment and the Industry, Bucharest, Romania, 189-196.

Kim L., Arama G.M., (2018), Ecological risk prediction in relation to the potential detrimental consequences at disposal of different industrial wastes, *Environmental Engineering and Management Journal*, **17**, 2201-2210.

Kim L., Muresan A.M., Cuciureanu A, Guta D., Arama M., Cristea N.I., Dediu, V., (2017), *Experimental Models of Characterization and Analysis of Industrial Waste*, 20th Int. Symp. The Environment and the Industry, Bucharest, Romania, 142-150.

Kim L., Arama G.M., Cuciureanu A., Guta D., (2018a), Handling specific issues of waste hazardousness evaluation according to waste type, *Environmental Engineering and Management Journal*, **17**, 2945-2956.

Kim L., Stanescu B., Cuciureanu A., Arama M-G., Traistaru G.A., (2018b), *Recent Approaches Regarding the Selection of Appropriate Methods for the Characterization and Analysis of used Oils in Order to Assess the Metals Content*, Int. Multidisciplinary Scientific Geo Conf. Surveying Geology and Mining Ecology Management, SGEM, Avena, 18 (4.2), 121-128.

Lee K.H., (2005), *First Course on Fuzzy Theory and Applications*, In: *Advances In Intelligent System And Soft Computing*, Kacprzyk J. (Series Ed.), Springer - Verlag Berlin Heidelberg New York.

Plerou A., Vlamou E., Papadopoulos B., (2016), Fuzzy logic models in epidemic control, *Precision Medicine*, **1**, 1-6.

Serbanescu A., Barbu M., Nicolescu I., Arama G.M., (2018), *Low Heating Value Prediction from Proximate Analysis for Sewage Sludge Samples*, 21st Int. Symp. The Environment and the Industry, Bucharest, Romania, 242-249.

Yang M-S, Chiang Y-H, Chen C.-C. Lai C-Y, (2008), A fuzzy k-partitions model for categorical and its comparison the GoM model, *Fuzzy Sets and Systems*, **159**, 390-405.

Zadeh L.A., (1975a), Fuzzy logic and approximate reasoning, *Synthese*, **30**, 407-428.

Zadeh L.F., (1975b), The concept of a linguistic variable and its application to approximate reasoning – III, *Information Sciences*, **9**, 43-80.

Zadeh L.F., (2008), Fuzzy logic, *Scholarpedia*, **3**, 1766, http://doi.org/10.4249/scholarpedia.1766.

Zimmermann H-J., (2010), Fuzzy set theory, *WIREs Computational Statics*, **2**, 317 -332.