Multicriteria solutions for environmental and waste management

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***Abstract* —** The decision making methodology for sustainable environmental management should include estimation of cumulative, interactive effects over time caused by current and foreseeable actions, and searching for a balance of the ecological, social and economic dimensions. The main aim is to capture all relevant foreseeable impacts in their most appropriate and representative units. Practical decision problems are often characterized by several noncommensurable and competing (conflicting) criteria, with no solution satisfying all criteria simultaneously. The multicriteria decision making method VIKOR could be applied for ranking alternatives and selecting compromise solution from the set of alternatives. The increasing public concern about environmental quality forces the development of evaluation models and the implementation of improvement strategies. Air, water and land pollution, and particularly waste management, are considered in this paper as the issues related to environmental protection. Several solutions are mentioned showing the complexity of solving environmental protection tasks. Multicriteria decision making for municipal solid waste management in the region of Novi Sad is presented as an illustrating example.

Keywords—Environmental protection, waste management, multicriteria decision, VIKOR method

I. Introduction

Humans are the driving force behind urban ecology and influence the environment in a variety of ways, such as modifying land surfaces and waterways, deforestation, and growing pollution. A large demand for chemical use by industry, construction, agriculture, and energy providing services have a substantial impact on environment, resulting in phenomena such as acid rain, eutrophication, and global warming. Wastes from large urban centers can drive biogeochemical cycles on a global scale. Due to the pressures of population and technology, the biophysical environment is being degraded, sometimes permanently. Formal environmental protection was stimulated by the United Nations Conferences. Following this, the governments began establishing environmental protection agencies. Their jurisdiction is similar and covers pollution control, land/water use, and waste management. The increasing public concern about environmental quality forces the development of evaluation models and the implementation of improvement strategies.

Air, water and land pollution, and particularly waste management, are considered in this paper as the issues related to environmental protection. The multicriteria decision making methodology is introduced in Section 2. Section 3 considers four issues related to environmental protection. In Section 4, multicriteria decision making for municipal solid waste management in the region of Novi Sad is presented, illustrating alternatives generation, formulation of criteria functions, evaluation of alternatives in terms of criteria, application of the VIKOR method and the proposition of final solution.

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II. Multicriteria Solution by the VIKOR Method

Practical decision problems are often characterized by several noncommensurable and competing (conflicting) criteria, with no solution satisfying all criteria simultaneously. Applying multicriteria decision making (MCDM), the solution (compromise) can be determined, which can help decision makers to reach a final decision.

The use of multicriteria (or multiattribute) approach, as a framework for sustainable environmental protection, has several desirable properties: the main aim is to capture all relevant foreseeable impacts in their most appropriate and representative units, establishing the hierarchy of indicators as a systematic way to perceive the entire set of indicators, and the relative importance of indicators can be used (such as weights). The indicators could be noncommensurable, such as: quantitative economic indices (monetary units), quantitative technical (engineering) measures (kg, sec, m), and qualitative indices (grades or scores). Indicators of sustainable environmental protection should be identified and a hierarchy will be constructed with the following main objectives: economy (costs and benefits), protection of natural environment, social acceptability, and institutional. In many cases, linkages among objectives lead to potential conflicts. Such cases reinforce the need to interpret results in a balanced and integrated manner.

For each main objective the indicators for second levels will be identified. For example, social acceptability could include: personal and family health, perceiving risk related to environment degradation, awareness of new management type, willing to contribute to environmental protection. The set of criteria (objectives) is constructed defining indicators for each criterion.

The alternatives of environmental protection should be evaluated in terms of formulated criterion functions. The VIKOR) method is introduced as one applicable technique to implement within MCDM.

The VIKOR method was developed as a multicriteria decision making method to solve a discrete decision problem with noncommensurable and conflicting criteria. This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision.

The compromise solution $F^c = (f_1^c, ..., f_n^c)$ is a feasible solution that is the "closest" to the ideal solution F^* (the best values of criteria). Here, compromise means an agreement established by mutual concessions, represented by $\Delta f_i = f_i^* - f_i^c$, $i = 1,\ldots,n$.

The alternatives are evaluated according to all established criteria, resulting in performance matrix $|f_{ij}|$, where f_{ij} is the value of the i-th criterion function for the alternative A_j; n is the number of criteria; J is the number of feasible alternatives.

The alternatives are ranked by the values Q_j, j=1,...,J in decreasing order.

$$Q_j = v(S_j - S^*)/(S^- - S^*) + (1-v)(R_j - R^*)/(R^- - R^*)$$

where:

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij})/(f_i^* - f_i^-) \quad (1)$$

$$R_j = \max_i [w_i (f_i^* - f_{ij})/(f_i^* - f_i^-)] \quad (2)$$

$f_i^* = \max_j f_{ij}$, $f_i^- = \min_j f_{ij}$, if the i-th function represents a benefit; $f_i^* = \min_j f_{ij}$, $f_i^- = \max_j f_{ij}$, if the i-th function represents a cost; $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$; w_i are the weights of criteria, expressing the DM's preference as the relative importance of the criteria; v is introduced as a weight for the strategy of maximum group utility, whereas 1-v is the weight of the individual regret, here $v = (n + 1)/ 2n$.

The VIKOR software proposes the best ranked alternative $A^{(1)}$ as a compromise solution, or a set of compromise solutions if several (M) alternatives are "in closeness" (close to the best ranked alternative), $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M, $DQ = 1/(J-1)$.

The VIKOR method is an effective tool in multicriteria decision making, particularly in situations where the decision maker is not able to express his/her preference at the beginning of system design. The obtained compromise solution could be accepted by the decision makers because it provides a maximum group utility of the "majority" (represented by min S, Equation (1)), and a minimum individual regret of the "opponent" (represented by min R, Equation (2)). The solution $A_S^{(1)}$ obtained by the minimization of the distance S in the equation (1) is

$$A_S^{(1)} = agr \min_j \sum_{i=1}^{n} w_i d_{ij} = agr \max_j \sum_{i=1}^{n} w_i f_{ij} / \left| f_i^* - f_i^- \right| .$$

It provides maximum group utility for the majority. The solution $A_R^{(1)}$ obtained by the minimization of the distance R in the equation (2) is

$$A_R^{(1)} = \arg\min_j \max_i (w_i d_{ij}) .$$

It provides minimum of maximal regret of the opponent. The solution $A_Q^{(1)}$ obtained by the minimization of the weighted distance Q provides compromise between the above two decision strategies.

The compromise solutions could be the base for negotiation, involving the decision makers' preference by criteria weights.

The basic ideas of VIKOR had developed by Serafim Opricovic, in his Ph.D. dissertation in 1979, and an application was published in 1980 [3]. The name VIKOR appeared in 1990 at national symposium (from Serbian: VIseKriterijumska Optimizacija i Kompromisno Resenje, that means: Multicriteria Optimization and Compromise Solution, with pronunciation: *vikor*). The paper [12] contributed to the international recognition of the VIKOR method; it was identified by Thomson Reuters *Essential Science Indicators*[SM] as the most cited paper in the field of Economics and Management (*Science Watch*, Apr.2009).

There are situations when the evaluation of alternatives must handle the imprecision of established criteria, and the development of a fuzzy multicriteria decision model is necessary to deal with either "qualitative" (unquantifiable or linguistic) or incomplete information. Fuzzy ranking methods have been developed that can be used to compare fuzzy numbers, but this is still an interesting research area.

There are two approaches to MCDM in a fuzzy environment, "conventional" and "fuzzy". The conventional approach is based on a nonfuzzy decision model, whereas the fuzziness dissolution (defuzzification) is performed at an early stage. The fuzzy approach is based on processing fuzzy data for decision making, then dissolving the fuzziness at a later stage. In both cases, diffuzification is necessary since MCDM results must provide a crisp conclusion. Defuzzification is selection of a specific crisp element based on the output fuzzy set, and it also includes converting fuzzy numbers into crisp scores. There are several defuzzification methods, although the operation defuzzification can not be defined uniquely.

The Fuzzy VIKOR method is developed as a fuzzy MCDM method to solve a discrete fuzzy multicritea problem with noncommensurable and conflicting criteria (Opricovic 2011). A numerical example illustrates an application of Fuzzy VIKOR to water resources planning, aiming to numerical justification. Comparisons of the results by different methods are presented.

III. Environmental protection

Environmental protection is a practice of protecting the natural environment on individual, organizational or governmental levels, for the benefit of both the natural environment and humans. Due to the pressures of population and technology, the biophysical environment is being degraded, sometimes permanently. Formal environmental protection was stimulated by the United Nations Conferences. Following this, the governments began establishing environmental protection agencies. Their jurisdiction is similar and covers pollution control, land/water use, and waste management. Protection of the environment is needed due to various human activities. Air, water and land pollution, and waste production are some of the issues related to environmental protection. Protecting air, water and land from negative impacts of wastes became a goal of environmental protection. Wastes from urban centers, especially large urban centers in developed nations, can drive biogeochemical cycles on a global scale.

A. Air Quality

The concentration of population and industrial development in many urban areas have led to deterioration of the urban environment and increasing public concern about environmental quality, forcing the development of evaluation models and the implementation of improvement strategies. One type of models includes quantifiable measures with data obtained through monitoring or surveys, and the other is generally based on people's preferences.

There are studies of multicriteria analysis of environmental quality in large cities. The results indicate air quality as main public concern. The deterioration of air quality in metropolitan area is caused by different pollutant sources, which are divided into two categories: mobile pollutant sources, which are emissions from motor vehicles; and immobile pollutant sources, such as factories, construction work, etc. [18]. The alternatives are the measures to improve air quality, for example, increasing the traffic flow efficiency, reducing traffic flow during peak hours, encouraging the use of low-pollution fuel, improving and encouraging travel by mass transportation, elimination of old vehicles, etc. The alternatives were ranked according to the established criteria, for example, implementation costs, cooperation of government administration, social equity, acceptance by non-polluters, acceptance by polluters, and amelioration of air quality. The expert evaluation approach could be used, since quantified information for the improvement strategies is difficult to obtain. Experts may judge the effects of each measure of improvement strategy. The top ranked alternatives in [18] are the use of low-pollution fuel and establishing rigid standards for the immobile polluters.

Air quality and odor control are addressed as critical elements for sustainable waste management in the paper [2[. The issue is concerned in presence of incinerators, for air pollution control, and landfill, mainly for odor, but it is usually neglected when segregated dry waste treatment is involved. A modern segregated waste treatment plant, already compliant with regulations requirements regarding indoor air quality, is taken as a case study to prove the effectiveness of a biotechnological treatment for air pollution and odor control. The system is based on bio-oxidizers that provide internal air-mixing and capture particulates and gases. Both gaseous contaminants and particulate matter appear to be effectively captured and treated by the system.

B. Sustainable Land use

Land is very important resource, but this resource has been poorly managed and not protected in recent decades. The physical, chemical and biological condition of the soils has deteriorated owing to irrational land use, common practice of clear-felling of forests, disregard of soil protection measures, improper cultivation techniques on slopes and hilly areas. Unprofessional fertilization, atmospheric acid sedimentation, the use of different acidic by-products and wastes, and the lack of liming caused an increase in soil acidification. Applying chemicals in agriculture we pollute soil and water sources (surface and underground). There is no appropriate methodology for evaluating sustainable land use, encompassing all biophysical and socioeconomic criteria. The future projects should improve the state of the art emphasizing that the land is not only commercial products but, rather, a heritages that must be protected, defended and treated as such. This could contribute very much sustainable land-use. However, the existing scientific, economic and legal instruments are currently beset by serious methodological shortcomings, hampering the implementation of strategies. There are diverse conditions and needs in the countries that require different specific solutions in sustainable development. This diversity should be taken into account in the planning and execution of measures to ensure protection and sustainable use of natural resources. Decisions should be taken as close as possible to the locations where natural resources are affected or used. Priority should be given to measures adjusted to regional and local conditions.

A particular example is presented in the article [11]. A multicriteria model is developed for analyzing the planning strategies for reducing the future social and economic costs in the area with potential natural hazard. The developed multicriteria decision making procedure consists of generating alternatives, establishing criteria, assessment of criteria weights, and application of the compromise ranking method (VIKOR). The alternatives are the scenarios of sustainable hazard effects mitigation, generated in the form of comprehensive reconstruction plans, including the redevelopment of urban areas and infrastructures, multipurpose land-use, and restrictions on building in hazardous areas. The plans have to be evaluated according to the criteria representing: public safety, sustainability, social environment, natural environment, economy, culture, and politics. The multicriteria model treats all relevant conflicting affects and impacts in their representative units. The evaluation of alternatives is implicated with imprecision (or uncertainty) of established criteria, and the fuzzy multicriteria model is developed to deal with "qualitative" (unquantifiable or linguistic) or incomplete information.

The application of this model is illustrated with the post-earthquake reconstruction problem in Central Taiwan; including the restoration concerning the safe and serviceable operation of "lifeline" systems such as electricity, water, and transportation networks, immediately after a severe earthquake [11]. Long-term reconstruction projects for earthquake-affected areas are needed to provide data for evaluation of alternative development plans. Due to the lack of original data, the data from the literature are used as supplementary information. The "921" earthquake in Central Taiwan in 1999 had a magnitude of M_L=7.3. The epicenter was located in Nantou County. In this area there are five main faults indicating the potential earthquakes, and making the regional planning a more difficult task. For multicriteria analysis of reconstruction plans, the alternatives (scenarios) of post-earthquake reconstruction could be generated using the information related to “system parameters” as follows.

s_1, s_2, s_3 - as same as for the “921” earthquake epicenter;

s_4 - number of reallocated settlements: from 0 up to 5000 houses, in the towns near the faults;

s_5 - land-use types: existing plan; more forestry, agriculture, and recreation areas; hydropower from small-dam cascades;

s_6 - development regulations: zoning, to ban construction within the hazard area, either side near the fault line; different regulations for urban and rural areas;

s_7 - fiscal policies: insurance, income tax;

s_8 - construction techniques: buildings may be restricted to one or two floors near the fault zone, “smart structures” and “structural optimization” could be considered for this area.

Using different values of the parameters *s*, 5 alternative scenarios are generated. The alternatives are evaluated according to the established criteria: reconstruction costs, gross dom. production, destroyed houses, damaged houses, restoration ability, sustainability, public acceptability, government preference.

The multicriteria optimization method VIKOR is applied to help decision makers achieve an acceptable compromise. The compromise solution is determined which could be accepted by the decision makers because it provides a maximum “group utility” of the “majority”, and a minimum individual regret of the “opponent”.

The results of multicriteria optimization could indicate the new plan and measures for improving global safety within the area with potential natural hazard. To answer the questions how and when to implement the land-use plan over study area, the research should continue by solving the allocation and scheduling problem under budgetary constraints

A similar approach could be applied for the other area with potential natural hazard (flood, tornado, or drought).

Postindustrial landscape redevelopment is considered as a meta-study by examine the design of large urban surface [5]. This meta-studies process facilitates building landscape architecture theory providing design principles and norms. The paper put forward noteworthy ideas regarding the importance of postindustrial land transformation to the overall land management. It facilitated the identification of a set of planning and design principles that contribute to the sustainability of the land use planning, and to the multicritera decision making within land management.

C. Water Management

The surface and underground waters available for utilization has decreased significantly, and their quality has deteriorated [7]. Pollution of subsurface waters can mainly be characterized with the high concentration of nitrates, which is due to the lack of sewage network in settlements and large animal farms and improper fertilizer and manure use. Waters in many countries are under increasing pressure from the continuous growth in demand for many different purposes [6]. More and more water is needed for irrigation, requiring large systems and new methods [3]. Applying chemicals in agriculture we pollute soil and water sources (surface and underground).

The EU's Water Framework Directive (2000) stipulates that a programme of schemes is to be laid down in a management plan for each river basin by 2010 which will ensure all ground water and surface water is of a “good status”[18]. For the purposes of environmental protection there is a need for a greater integration of qualitative and quantitative aspects of both surface waters and groundwaters, taking into account the natural flow conditions of water within the hydrological cycle. The article 16 of WFD defines Strategies against pollution of water. The European Parliament and the Council shall adopt specific measures against pollution of water by individual pollutants or groups of pollutants presenting a significant risk to or via the aquatic environment, including such risks to waters used for the abstraction of drinking water. For those pollutants measures shall be aimed at the progressive reduction and, for priority hazardous substances, at the cessation or phasing-out of discharges, emissions and losses. The article 17 defines Strategies to prevent and control pollution of groundwater. In order to identify the impact of human activity on waters the following is necessary:

- Estimation and identification of significant point and diffuse source pollution, from urban, industrial, agricultural and other installations and activities.
- Estimation and identification of significant water abstraction for urban, industrial, agricultural and other uses, including seasonal variations and total annual demand, and of loss of water in distribution systems.
- Estimation and identification of the impact of significant water flow regulation, including water transfer and diversion, on overall flow characteristics and water balances.
- Identification of significant morphological alterations to water bodies.
- Estimation and identification of other significant anthropogenic impacts on the status of surface waters.
- Estimation of land use patterns, including identification of the main urban, industrial and agricultural areas and, where relevant, fisheries and forests.
- Assessment of the susceptibility of the surface water status of bodies to the pressures identified above.
- Use the information collected above, and any other relevant information including existing environmental monitoring data, to carry out an assessment of the likelihood that surface water bodies within the river basin district will fail to meet the environmental quality objectives.
- Utilize modelling techniques to assist in such an assessment.
- For those bodies identified as being at risk of failing the environmental quality objectives, optimize the design of both the monitoring programmes and the programmes of measures.

This could contribute very much sustainable water use. However, the existing scientific, economic and legal instruments are currently beset by serious methodological shortcomings, hampering the Directive's implementation. There are diverse conditions and needs in the Community that require different specific solutions in sustainable development. Decisions should be taken as close as possible to the locations where waters are affected or used. Priority should be given to measures adjusted to regional and local conditions. The success of these projects relies on information, consultation and involvement of the public, including users [15]. There were attempts to implement WFD in Serbia [8].

An economical–ecological problem related to the management of a wastewater treatment system is solved in the paper [1]. A wastewater treatment system consisting of several purifying plants is considered. It is assumed that each of the plants is controlled by a different organization (municipal governments), and that each of them has to take care of a small number of sensitive areas, in such a way that a penalty is imposed on the plant if the water pollution levels in one of its associated zones is greater than a threshold level. The wastewater treatment problem consists of finding the purification strategy in each plant minimizing the cost functional (purification cost and penalties) at every plant. The problem is formulated as a multi-objective (multicriteria) optimal control problem, looking for Pareto-optimal solutions. A Pareto-optimal solution is a solution S_p if there does not exit any other solution S better than S_p according to all objectives (criteria). When assuming domestic discharges, it is usual to take faecal coliform (FC) bacteria as indicator of the water quality. The management of a purification plant is equivalent to determine the amount of FC discharged after purification. Pareto-optimal solutions provide with purification strategies improving the results for the plants. The FC concentrations corresponding to those solutions are also obtained.

An application of MCDM method to water resources planning of Serbian system is presented in [13]. The comprehensive analysis was required to resolve conflicting technical, social and environmental features. Even if the topographic surveys confirm that the required reservoir capacity is available, a hydrological solution may conflict with environmental, social, and cultural features. The Fuzzy VIKOR method was applied to evaluate alternative systems on the Mlava River. The alternatives were generated by varying two system parameters, dam site and dam height. Six alternatives were selected for multicriteria optimization. The designed reservoir systems are evaluated according to four criteria: investment costs (in 10^6 US$) ,water supply discharge - yield (m^3/s), social impact (%) on urban and agricultural area expressing local regret as percentage of the regret in the alternative with maximum social impact, impact on the monastery Gornjak is graded by the experts. This numerical example illustrates an application of the Fuzzy VIKOR method to water resources planning, aiming to numerical justification. It is an intention to illustrate the conceptual and operational validation of the application of this method in real world problem.

D. WasteMmanagement

Waste management is the collection, transport, processing or disposal, managing and monitoring of waste materials. Widely accepted hierarchy of priorities is as follows:

- prevention of waste material being created
- reduction by appropriate technologies and products
- separation of waste materials
- reuse of waste materials
- recycling of waste materials by reprocessing into new products
- incineration or thermal treatment to generate heat or electricity
- composting to decompose organic waste material, recycling as compost/fertilizer
- disposal of waste in a landfill.

The aim of this hierarchy is to extract the maximum practical benefits and to generate the minimum amount of waste.

The waste is produced by different human activities. Waste represents a considerable loss of resources both in the form of materials and energy. Reducing the material intensity of production and consumption of goods and services is essential to environmental protection and resource conservation. Reductions in intensity of material use can be achieved by more efficient use of natural resources in production and consumption, by recycling used and waste material, and by shifts in consumption patterns to less material intensive goods and services. The treatment and disposal of the generated waste may cause environmental pollution and expose humans to harmful substances and bacteria, and therefore impact on human health. The optimization subject is the proportion of waste generated (collected) which is recycled, composted, incinerated, or landfilled on a controlled site. The proper treatment and disposal of waste is important from an environmental and social viewpoint but can be an economic burden on industries, municipalities and households. The amount of waste recycled and composted reduces the demand for raw materials, leading to a reduction in resource extraction. There may also be a benefit of increased income generation for the urban poor through recycling schemes.

Environmental performance at waste management is achieved by consuming less, emitting less, reuse, achieving financial objectives, protecting the environment, complying with all rules and regulations. Environmental protection criteria are conflating with economic. For example, high GDP growth is generally considered a positive sign of economic development, but it is often associated with higher energy consumption, exploitation of natural resources and negative impacts on environmental resources. Implementation of environmental protection measures needs financial resources, although this could not be the excuse for the negligence in waste management, particularly in waste disposal. The bad situation with waste disposal forces the developing countries to improve waste management. In Serbia, there are projects related to waste management, for example, the project of regional hygienic landfill for municipal solid waste with recycling center in Sremska Mitrovica [9].

A construction waste management model is considered in the paper [4]. Four components are identified in the conceptual framework: regulation, policy, technology and guideline. These four measures are used to ensure the 3R strategy (reduce, reuse, recycle) being implemented efficiently. From the conceptual framework indicates that less waste to dispose and more reuse and recycle of waste should be done. The framework helps in engaging all stakeholders to collaborate with the government in construction waste management implementation. Government is called to cut off the serious issues of waste that arise during construction.

The paper by Tsaur (2014) concludes the recovery stations hold a key role in the recycling process [17]. The study finds positive relationships between motivation to recycle and satisfaction with recovery stations, between satisfaction with recovery stations and willingness to recycle, and between motivation to recycle and willingness to recycle. A promote strategy to get unmarried people to recycle is proposed.

A framework of Port solid waste management is presented in the paper [14]. This article aims at presenting a methodology for the collection, transportation, treatment and disposal, with emphasis on waste classification and segregation, and automation technology that makes possible the implementation of the management plan.

Air quality and odor control are addressed as critical elements for sustainable waste management in the paper [2[. The issue is concerned in presence of incinerators, for air pollution control, and landfill, mainly for odor, but it is usually neglected when segregated dry waste treatment is involved. A modern segregated waste treatment plant, already compliant with regulations requirements regarding indoor air quality, is taken as a case study to prove the effectiveness of a biotechnological treatment for air pollution and odor control. The system is based on bio-oxidizers that provide internal air-mixing and capture particulates and gases. Both gaseous contaminants and particulate matter appear to be effectively captured and treated by the system.

Here, a special focus is put on the waste treatment, with an illustrative example. The task is to decide on the proportion of municipal solid waste generated (collected) which is recycled, composted, incinerated, or landfilled on a controlled site.

IV. Illustrative Example

Municipal solid waste management in the region of Novi Sad has been considered [10], [16]. The waste generation is constantly increasing due to several factors such as growing population and industrial development, as well as changes in the consumer habits.

The objective is to develop the methodology to assess the efficiency of alternative programs both environmentally and from the economic and social perspectives. The parameters for optimization model are the percentages of waste which are recycled, composted, incinerated, and landfilled on a controlled site. The amount of waste recycled and composted reduces the demand for raw materials, leading to a reduction in resource extraction. There may also be a benefit of increased income generation for the urban poor through recycling schemes.

This model will help decision makers optimize the performance of their waste management programs. The alternatives are generated combining the parameters for optimization of waste treatment, and they are presented in Table 1. For example, 100 % (or 99 %) of landfilling means total collected waste goes to landfill, or 44 % of incineration means the percent of total waste treated by incineration. Constraints are seen as high-priority objectives, which must be satisfied in the alternatives generating process.

The formulation of the optimization criteria is based on the indicators. The indicators could be grouped to:

Social: health, security, education, equity, housing, and population

Environmental: atmosphere, land, rivers, seas, fresh water and biodiversity

Economic: economic structure and consumption/production patterns

Institutional: institutional framework and institutional capacity.

For example, indicators for the operation cost as an economic criterion are:

Operation costs for disposal of waste in a landfill (well-managed and hygienic), €/Ton

Operation costs for recycling of waste materials, €/Ton

Operation costs for composting (recycling as compost/fertilizer), €/Ton

Operation costs for incineration to generate heat, €/Ton

Operation costs for incineration to generate electricity, €/Ton.

The operation cost is formulated as follows:

$$f_4 = \sum_a c_a W p_a / 100$$

where: c_a is unit operation cost for *a*-th activity, W total yearly waste, p_a is the percent of waste W treated by the *a*-th activity.

The most relevant indicators could be chosen through a selection process that included opinions from experts, literature review based on relevance and applicability to different waste program settings.

Three questionnaires are designed in order to collect information related to the opinion and preference of decision makers at national, regional and local levels, and the data for existing system from managers.

The alternatives are evaluated according to all established criteria, resulting in performance matrix $\left| f_{ij} \right|$, where f_{ij} is the value of the *i*-th criterion function for the alternative A_j; *n* is the number of criteria; *J* is the number of feasible alternatives. The evaluation results obtained by different procedures are presented in Table 2.

Table 1. Alternatives of treatment system

Activity	Alternatives					
	A1	A2	A3	A4	A5	A6
Landfilling % of collec.w.	99	99	69	0	30	30
Recycling %	1	1	10	1	20	6
Composting %	0	0	30	0	0	0
Incineration %	0	0	0	99	44	44

Table 2. The values of criterion functions and weights

Criteria	Alternatives	Weights

	Ext.	A1	A2	A3	A4	A5	A6	SW1	SW2	SW3
N emissions	Min	332	84	206	0	0	0	1	1	2
CO_2 emissions	Min	294	243	233	0	0	0	1	1	2
TOC/ Tot.organ.Carbon	Min	116	116	99	2	160	160	1	1	2
Recycling %	Max	1	1	10	1	20	6	1	2	3
Landfilled %	Min	99	99	72	30	30	44	1	2	2
Landfill m^3/(capita ,y)	Min	0.4	0.4	0.28	0.08	0.09	0.13	1	1	1
Operation costs €/t	Min	78	90	84	120	107	136	1	2	1
Generated ener.TJ	Max	0	0	0	1188	1080	1080	1	1	1
Consumed ener.TJ	Min	14.9	17.	20.	18.	55.	164.	1	1	1

Source: Miloradov et al. 2013 [10].

The results by the VIKOR method are determined with data from Table 2.

The results by the VIKOR method with equal criteria weights $w_i = 1$:

Ranking list: **A4 (0.065), A5 (0.093),** A6 (0.524), A3 (0.662, A2 (0.869), A1 (1.0).

Ranking is performed by the values Q, in parentheses.

VIKOR proposes set of compromise solutions {A4, A5}, because they are in closeness

The results by the VIKOR method with the weights {1,1,1,2,2,1,2,1,1}, giving importance to f4 – Level of recycling, f5 – Total landfilled waste after treatments, f7 – Operation costs:

Ranking list: **A5 (0.0)**, A3 (0.4), A4 (0.561), A6 (0.783), A2 (0.959), A1 (1.0).

VIKOR proposes alternative A5 as the compromise solution.

The results by the VIKOR method with the weights {2,2,2,3,2,1,1,1,1}, giving importance to f1 – Nitrogen emissions, f2 – CO_2 emissions, f3 – Total organic carbon, f5 – Total landfilled waste, and particularly to f4 – Recycling:

Ranking list: **A5 (0.137)**, **A3 (0.300)**, A6 (0.415), A4 (0.516), A2 (0.910), A1 (1.0).

VIKOR proposes set of compromise solutions {A5, A3}, because they are in closeness

Observing the positions of proposed compromise solutions, we may conclude that A5 is the most stable one, and alternative A5 is proposed for final decision.

Selected treatment system (A5) consists of mechanical-biological treatment (MBT) plant, incineration in cement kiln, sanitary landfill, and market for recycling material. From collected municipal soled waste 6 % is recycled. The main part goes to MBT plant. After MBT, 44% of collected waste goes as a fuel in cement kiln, 30 % goes to landfill, and one part is gases emissions. In cement factory, 14% is used as clinker for cement production, and it is counted as recycling.

Required landfill volume is 42000 m^3 per year, and treatment system cost is Euro 20 million per year. Comparing with existing landfilling of 100% of waste, the new landfill is 4.5 times smaller, and system is 20% more expensive.

V Conclusion

Environmental protection is considered as a practice of protecting the natural environment on individual, organizational or governmental levels, for the benefit of both the natural environment and humans. Protection of the environment is needed due to various human activities. Protecting air, water and land from negative impacts of wastes became a goal of environmental protection.

The decision making methodology for sustainable environmental management should include estimation of cumulative, interactive effects over time caused by current and foreseeable actions, and searching for a balance of the ecological, social and economic dimensions. Compromising is necessary when goals are clearly incompatible and mutually exclusive, decision makers have equal power, and partial satisfaction maybe better and feasible. In negotiations, the parties realize the potential of a compromise and can assess main features of the agreement established by mutual concessions. Compromising can be supported by a multicriteria decision making methods and tools, such as the VIKOR method. The VIKOR method assumes all parties acting as one rational decision maker in compromising, and the preference is expressed by the weights of criteria. The obtained compromise solution could be approved by the decision makers because it provides a maximum group utility of the “majority” and a minimum individual regret of the “opponent”. The main contributions of VIKOR to conflict resolution are: consideration of the decision making process in addition to the result; the use of criteria which is more meaningful for decision makers than utilities; search for the set of compromise solutions rather than one solution; and, interactivity which allows decision makers to participate in and control the decision process (by weights).

The main activities for the implementation of the solution will take place in the context of environmental protection project led by local authorities. Priority should be given to measures adjusted to regional and local conditions. It is necessary to establish an integrated monitoring and management system in order to maintain high status of environment. Also, the success of the project relies on information, consultation and involvement of the public.

A more general ecosystems approach to environmental resource management and environmental protection aims to consider the complex interrelationships of an entire ecosystem in decision making rather than simply responding to specific issues and challenges. The decision making would be a collaborative approach to planning and management that involves a broad range of stakeholders across all relevant governmental departments, as well as representatives of industry, environmental groups and community. To apply the VIKOR method, the management alternatives should be evaluated in terms of established criteria for the stated management problem.

REFERENCES

[1] Alvarez-Vázquez, L.J., García-Chan, N., Martínez, A., Vázquez-Méndez, M.E., Pareto-optimal solutions for a wastewater treatment problem, *Journal of Computational and Applied Mathematics*, Vol. 234, 2010, pp. 2193–2201.

[2] Bonoli, A., Zanni, S., Indoor air quality in waste treatment: environmental issue and biotechnology application for air pollution containment, a case study, *WSEAS Transactions on Environment and Development*, Vol. 10, 2014, pp. 529-541.

[3] Duckstein, L., Opricovic, S. Multiobjective Optimization in River Basin Development, *Water Resources Research*, Vol.16, No.1, 1980, pp. 14-20.

[4] Ismam, J.N., Ismail, Z., Sustainable Construction Waste Management Strategic Implementation Model, *WSEAS Transactions on Environment and Development*, Vol. 10, 2014, pp. 48-59.

[5] Loures, L., Burley, J., Panagopoulos, T., Postindustrial Landscape Redevelopment: addressing the past, envisioning the future, *International Journal of Energy and Environment* (NAUN), Vol.5 (5), 2011, pp. 714-724.

[6] Miloradov, M. Planning and Management of Complex Water Resources Systems in Developing Countries, *ASCE Journal of Water Resources Planning and Management*, Vol.118, No.6, 1992.

[7] Miloradov, M., Marjanovic, P., Cukic Z. Water Resources Assessment as a Basic Tool for Sustainable and Environmental Sound River Basin Management, *Water Sciences and Technology*, Vol. 32, No.5-6, 1995, pp.149-164.

[8] Miloradov, M., Prohaska, S. *Measurement and Monitoring System of Water in Vojvodina and River Basin Nadela*, Workshop G_2G-project, Implementation of the EU Water Framework Directive in Serbia, Novi Sad, 2010.

[9] Miloradov, M. *The project of regional hygienic landfill for municipal solid waste with recycling center in Sremska Mitrovica*, Hidrozavod DTD, Novi Sad, 2008.

[10] Miloradov, M., Opricovic, S. and Stanisavljevic, N., Technological development in environmental protection and waste management, part II-2 in the project: *Research of basic technological development possibilities in Vojvodina* (in Serbian), Academy of Sciences, Cultures and Arts of Vojvodina, Novi Sad, 2013.

[11] Opricovic, S., Tzeng, G.H. Multicriteria Planning of Post-Earthquake Sustainable Reconstruction, *the Journal of Computer-Aided Civil and Infrastructure Engineering*, Vol.17, No.3, 2002, pp. 211-220.

[12] Opricovic, S., Tzeng, G.H., The Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, *European Journal of Operational Research*, Vol.156, No.2, 2004, pp.445-455.

[13] Opricovic, S. Fuzzy VIKOR with an application to water resources planning, *Expert Systems with Applications* 38, 2011, pp. 12983-12990.

[14] Pereira, S.L., Fontana C.M.M., Fontana, C.F., Sakurai, C.A., Management of Port Solid Waste Framework, *International Journal of Energy and Environment* (NAUN), Vol.8, 2014, pp. 27-33.

[15] Solomon, U., A detailed look at the three disciplines, environmental ethics, law and education to determine which plays the most critical role in environmental enhancement and protection, *Environment, Development and Sustainability*, Vol.12, No.6, 2010, pp.1069-1080.

[16] Stanisavljevic, N., *Application of material flow analysis for modeling of waste management systems*, Ph.D. dissertation, Faculty of Technical Sciences, University of Novi Sad, 2012.

[17] Tsaur, R.C., Analysis of the Relationships among Motivation to Recycle, Willingness to Recycle, and Satisfaction with Recovery Stations in Taiwan, *WSEAS Transactions on Environment and Development*,Vol.10, 2014, pp. 26-34.

[18] Tzeng, G.H., Tsaur, S.H., Laiw, Y.D., Opricovic, S., Multicriteria Analysis of Environmental Quality in Taipei: Public Preferences and Improvement Strategies, *Journal of Environmental Management*, Vol.65, No.2, 2002, pp.109-120.

[19] Water Framework Directive, Directive 2000/60/EC of the European Parliament and of the Council, L 327/1, *Official Journal of the European Communities EN*, Luxembourg, 2000.

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