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THE EFFECT OF ENVIRONMENTAL INDICATORS ON THE WASTE TREATMENT SCENARIOS RANKING

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Abstract. *The selection of an appropriate waste treatment scenario is a complex problem in which a set of environmental, economic, and social criteria must be taken into account. Different waste treatment scenarios have different effects on the environment, which is expressed through a variety of environmental indicators. The main problem is to determine the indicators that clearly and fully express the most important influential factors. This paper presents a number of different environmental indicators and their influence on the waste treatment scenarios ranking. The study is carried out on the example of waste management in the city of Niš. Four scenarios are developed: the business as a usual scenario (meaning the landfilling of waste) and the three other scenarios with energy recovery and preservation of resources including composting organic waste with recycling inorganic waste, incineration of waste, and anaerobic digestion of waste. Four experiments were conducted in order to assess the influence of environmental indicators: the first experiment was done using four indicators, the second by using seven indicators, the third experiment by using nine indicators, and the fourth experiment by twelve indicators. The ranking of each scenario was performed on the basis of a multi-criteria analysis, the Analytic Hierarchy Process (AHP method). The obtained results have shown that the increasing number of environmental indicators has led to a change in the ranking of scenarios in terms of their impact on the environment. Namely, it is necessary to increase the number of environmental indicators to a number which will be sufficient to carry out the relevant waste treatment scenario ranking in terms of the impact on the environment.*

Key Words: *Environmental Indicators, Waste Treatment Scenarios, Multi-criteria Analysis, AHP Method*

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1. INTRODUCTION

In assessing the sustainability of waste treatment, several aspects should be taken into account: environmental, economic, and social. Each of them is expressed through specific indicators that can be identified as environmental, economic, and social.

Environmental indicators are essential tools for tracking environmental progress, supporting policy evaluation, and informing the public. An environmental indicator is defined as a number indicating the state and development of the environment or conditions affecting the environment. Indicators can be used descriptively for a scientific purpose or normatively for a political purpose [1]. For such purposes an indicator must be placed in a context that allows for an interpretation of its values. The essential characteristic of an indicator is that it is possible to interpret or evaluate its value. An indicator may be defined as a characteristic which, when measured repeatedly, demonstrates ecological trends and a measure of current state or quality of an area [2]. Some authors define an indicator as "a parameter or value that reflects the condition of an environmental (or human health) component, usually with significance that extends beyond the measurement or value itself, [and] when used alone or in combination, [the indicators] provide the means to assess progress toward one or more objectives" [3].

Different waste treatments have different effects on environment, which is expressed through a variety of environmental indicators. The anaerobic digestion offers a greatly increased reduction in net greenhouse gas (GHG) production compared with other technologies. Comparing incinerator facilities with energy recovery and landfill dispatching, the incinerator allows a greenhouse gas reduction of 360 $kgCO_2eq$/ t waste and in the case of a traditional landfill with no provision for landfill gas capture, the difference with respect to incinerators increases to 650 $kgCO_2eq$/t waste [4]. The greatest waste volume reduction is achieved with anaerobic digestion (95.69 %) compared with other waste treatments [5]. Gasification has provided by far the best energy recovery in terms of electrical product (1083 kWh/t), while anaerobic digestion has provided a relatively poor energy recovery (151 kWh/t) [4].

To assess the environmental impact of a certain waste treatment, it is necessary to carry out an adequate analysis of all influential environmental criteria. The main problem in the analysis is to determine the number of indicators that clearly and fully express the most important influential factors.

In this paper, four experiments were conducted in order to assess the influence of environmental indicators and their number, and thus four waste treatment scenarios were created. The first experiment was done using four indicators, the second by using seven indicators, the third experiment by using nine indicators and the fourth experiment by twelve indicators. The presented study was carried out on the example of waste management in the city of Niš. The ranking of each scenario was performed on the basis of a multi-criteria analysis, the Analytic Hierarchy Process (AHP method). The comparative results of the changes in scenario ranking obtained by increasing the number of different environmental indicators are presented.

2. ENVIRONMENTAL INDICATORS

Today a wide variety of environmental indicators is used. These indicators reflect trends in the environment just as they monitor the progress made in realizing environmental protection. In relation to policy-making, the environmental indicators are used for four main purposes: a) for supplying information on environmental problems in order to enable policy-makers to evaluate their seriousness; b) for supporting policy development and priority setting by identifying the key factors that cause pressure on the environment; c) for monitoring effects and effectiveness of policy responses, and d) for raising public awareness of environmental issues.

Since the early 1990s, the environmental indicators have gained in importance in many countries and in international forums. OECD countries have increasingly used a reduced number of indicators, so-called “key indicators”, selected from larger sets to report on major environmental issues [6]. Now, there are several sets of environmental indicators, each responding to a specific purpose. During the 1990s, the environmental indicators gained significant importance and are now widely used in OECD countries. They are used in reporting, planning, clarifying policy objectives and priorities, budgeting, and assessing performance. The OECD environmental indicators are relatively small sets of indicators that have been identified for use at the international level, and should be complemented by national indicators when examining issues at the national level [7]. These key indicators have been selected from the core ones included in the Core Set of Environmental Indicators [8] and are closely related to other environmental indicators sets. These indicators are divided into two groups. The first group includes climate change, ozone layer, air quality, and waste generation. The second group that involves natural resources includes freshwater quality, freshwater resources, forest resources, fish resources, energy resources, and biodiversity. Their selection has taken into account their policy relevance with respect to major challenges of the first decade of the 21st century, including pollution issues and those related to natural resources and assets, their analytical soundness and their measurability.

Most indicators presently used by nations are based on the DPSIR-framework. They are used to characterize the main environmental issues, such as climate change, acidification, toxic contamination and wastes in relation to the geographical levels at which these issues manifest them or on which they are managed. Indicators for the driving forces describe the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns. Primary driving forces are population growth and developments in the needs and activities of individuals. Through these changes in production and consumption, the driving forces exert pressure on the environment. Pressure indicators describe developments in release of substances (emissions), physical and biological agents, the use of resources, and the use of land by human activities. State indicators give a description of the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric CO_2-concentrations) in a certain area. Impact indicators are used to describe changes in these conditions. It is the change in the availability of species that influences human use of the environment. In terms of their strict definition, impacts can be only those parameters that directly reflect changes in environmental use functions by humans. As humans are a part of the environment, impacts also include health impacts. Response indicators refer to responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment [9].

According to the OECD data [7], average municipal waste generation intensities per capita in 2011 for OECD countries are 530 kg per capita, which is for 30 kg less than in 2005 and 20% less waste has been disposed of in landfills since 2000.

In order to evaluate the effects of different waste treatments on the environment, different environmental indicators have been used and different models have been developed. Greene and Tonjes [10] examine the common performance indicators to assess the environmental benefits of municipal waste systems in order to determine if there is agreement between them regarding which system performs best environmentally. The considered performance indicators are: GHG emission reductions, energy savings, landfill disposal rate, recycling rate, diversion rate, etc. The focus is placed on how indicator selection influences comparisons between municipal waste management programs and subsequent system rankings. Coelho et al. [11] have proposed a new concept: the Cleaner Treatment based on the Cleaner Production principles; they have developed the Cleaner Treatment Index (CTI) to assess environmental performance of waste treatment technologies. This model focuses on five major issues: environmental liabilities, climate change, greenhouse effect, soil, water and air pollution, energy and natural resources consumption. Manfredi and Goralczyk [12] have developed the macro-level waste management indicators in order to quantify and monitor the potential environmental impacts, benefits, and improvement possibilities associated with the management policies and strategies of a number of selected waste streams generated and treated in Europe. The waste management indicators were developed for the EU-27. Indicators were a combination of statistical waste data with emissions and resource life cycle data for the different elements of the waste treatment chain. The developed waste management indicators were: climate change midpoint, ozone depletion midpoint, human toxicity midpoint, particulate matter/respiratory inorganic midpoint, acidification midpoint, eutrophication terrestrial midpoint, eutrophication freshwater midpoint, eutrophication marine midpoint, ecotoxicity freshwater midpoint, land use midpoint, etc. Josimovic et al. [13] apply the multi-criteria evaluation method to carrying out a strategic environmental assessment for the Waste Management Plan for the city of Belgrade. The method is applied to the evaluation of the impacts of the activities planned in the waste management sector on the basis of the environmental and socioeconomic indicators of sustainability. The environmental indicators taken into consideration are: water (surface water and groundwater), air and climate change, soil, biodiversity and landscape. In order to rank four different options of municipal solid waste treatment alternatives from an environmental point of view, Herva and Roca [14] have applied two methods: (1) the ecological footprint (EF) as a single composite indicator and (2) multi-criteria analysis integrating the EF together with other material flow indicators related to water consumption, air emissions of organic compounds, air emissions of dusts, water emissions of suspended solids, and occupied landfill volume. To choose a solid waste management system using multi-criteria decision analysis, Hokkane and Salminen [15] have used the following environmental criteria: global effect (CO_2, CH_4, N_2O emissions), releases with health effects (heavy metal releases to air and water: lead (Pb), cadmium (Cd), arsenic (As), mercury (HG), dioxin and furan), acidificative releases (SO_2, NO_x), surface water dispersed releases.

In accordance with the given referential literature survey, twelve environmental indicators representing different effects of the waste treatment are selected in order to assess the impact of certain waste treatment on the environment (air, water and soil).

3. Diversity and Number of Indicators Research

Table 1 presents the composition of waste generated in the city of Niš. The data on generated waste are taken from the Waste Management Plan of the city of Niš in the period up to 2015 [16] and other previously published papers [5].

Table 1 The quantity of waste generated in the city of Niš (2010) [16]

Fraction	Production (t/year)	Percentage (%)
Food waste	24,298	33.70
Yard waste	7,494	10.40
Paper	11,031	15.30
Plastics	12,762	17.70
Glass	3,677	5.10
Metals	1,370	1.90
Other	11,464	15.90
Total	72,100	100.00

The largest part of the waste is organic waste (food and yard waste) – 44 %, while recyclable fractions make up 40 % of total waste.

3.1. Developed scenarios

Four scenarios were developed on the basis of the methods of waste treatment: recycling, composting, anaerobic digestion, incineration with energy recovered and waste disposal. The first scenario was the business as a usual scenario (meaning the landfilling of waste) in the city of Niš. The other three scenarios were created as scenarios with energy recovery and preservation of resources. Scenario 2 implied that all recyclable waste was recycled and organic waste was composted. Scenario 3 implied that all amount of glass and metal was recycled and other combustible waste was incinerated. Finally, Scenario 4 implied that all the waste (glass, plastics and metal) which was unsuitable for anaerobic digestion, was recycled, while other types of waste were sent to an anaerobic digester. Main variation factors of each scenario are given in order to evaluate environmental indicators. The annual distance driven by collection trucks was calculated according to the presumed location of the waste treatment facility. One location was presumed for the incinerator or anaerobic digester.

Scenario 1: Most waste (68,440 t) is disposed of in the landfill, 71 % of metal and glass (3,560 t) is recycled. Annual distance driven by collection trucks is 118,400 km. Trucks use diesel fuel; with fuel efficiency of 2.5 km/l. Energy consumed by landfill operation is 0.22 l/t of diesel fuel. Energy consumption at materials recovery facility: electricity 25 kWh/t, natural gas 0.264 m^3/t.

Scenario 2: Inorganic waste (28,840 t) is recycled (plastic, glass, paper and metal). Organic waste (31,790 t) is sent to in-vessel composting plant. Other waste (11,464 t) is disposed of in the landfill. Annual distance driven by collection trucks is 112,596 km. Energy consumption in composting process is 21 kWh/t of electricity.

Scenario 3: 100 % of glass and metal (5047 t) is recycled and residual waste (67,053 t) is sent to incineration with energy recovery (cogeneration plant). Annual distance driven by collection trucks is 108,149 km. Energy efficiency in cogeneration plant is 75%. Facility energy consumption is 70 kWh/t.

Scenario 4: 100 % of recyclable waste – glass, metal and plastic (17,809 t) are recycled. Other waste (54,291 t) is sent to anaerobic digestion plant for the purpose of electricity generation. Annual distance driven by co-mingled trucks is 108,149 km. The composition of produced biogas is CO_2 45%, CH_4 55%. Energy efficiency in anaerobic digestion process is 20%. Facility energy consumption is 22% of the produced energy.

3.2. Experiments description

There is no unique set of indicators. Whether a given set of indicators is appropriate depends on its use [7]. According to the OECD key environmental indicators [6], in order to assess the impact of certain waste treatment on the environment (air, water and soil), twelve indicators are selected. The selected indicators reflect the different impact of waste treatment on the environment in developed scenarios:

- climate changes – CO_2 Equivalents,
- air quality – acid gas emissions (SO_2 and NO_x), heavy metals in air (Pb), smog precursors (PM, VOCs, dioxins),
- freshwater quality – heavy metals in water (Pb, Hg) and organics in water (BOD),
- waste generation – waste volume reduction,
- energy resources – energy consumption.

GHG emissions (CO_2 Equivalent): Main concerns relate to effects of increasing atmospheric greenhouse gas (GHG) concentrations on global temperatures and the earth's climate, and consequences for ecosystems, human settlements, agriculture and other socio-economic activities. A GHG emission (CO_2 and methane) occurs mostly in waste landfilling and incineration.

Acid gases emissions (SO_2, NO_x emission): Main concerns relate to the effects of air pollution on human health, ecosystems, and buildings, and to their economic and social consequences. Human exposure is particularly high in urban areas where economic activities and road traffic are concentrated. Acid gas emissions (SO_2, NO_x) occur mostly in waste incineration.

Heavy Metal in air (Pb): Main concerns relate to the effects of air pollution on human health, ecosystems, and to their economic and social consequences. Human exposure is particularly high in urban areas where economic activities and road traffic are concentrated. A heavy metal emission in air (Pb) occurs mostly in waste incineration.

Smog Precursors (PM, VOCs, dioxins): Causes of growing concern are concentrations of fine particulates, VOCs, dioxins, toxic air pollutants episodes in both urban and rural areas. Smog Precursors (PM, VOCs, dioxins) occur mostly in waste incineration, recycling and composting.

Heavy Metals in water (Pb, Hg) and organics in water (BOD): Main concerns relate to the impacts of water pollution (acidification, toxic contamination) on human health, on the cost of drinking water treatment, and on aquatic ecosystems. Despite significant progress in reducing pollution loads from municipal and industrial point sources through installation of appropriate waste water treatment plants, improvements in freshwater quality are not always easy to discern, except for organic pollution.

Waste volume reduction: The main challenge is to strengthen measures for waste minimization, especially for waste prevention and recycling. Except landfilling, each waste treatment involves waste volume reduction.

Energy consumption: Main concerns relate to the effects of energy production and use on greenhouse gas emissions and on local and regional air pollution; other effects involve water quality, land use, risks related to the nuclear fuel cycle and risks related to the extraction, transport and use of fossil fuels.

In order to assess the impact of specific environmental indicators on the ranking of scenarios in terms of environmental impact, four experiments were performed. Table 2 presents the indicators that were monitored in the four experiments as well as the basis of evaluating the change in the results with respect to the changing number of indicators.

Table 2 Review of selected indicators

Indicators	First experiment	Second experiment	Third experiment	Fourth experiment
CO_2 Equivalent (t)	x	x	x	x
NO_x emission (t)	x	x	x	x
SO_2 emission (t)			x	x
Pb emission in air (kg)				x
Smog precursors – PM (t)		x	x	x
Smog precursors – VOCs (t)				x
Dioxins emission in air (TEQ) (g)		x	x	x
Pb emission in water (kg)	x	x	x	x
Hg emission in water (kg)			x	x
BOD emission in water (kg)		x	x	x
Waste volume reduction (%)	x	x	x	x
Energy consumption (GJ)				x

The first experiment examined the effect of **four indicators** in ranking scenarios. The selected indicators were: GHG emission (CO_2 Equivalent), acid gases emission (NO_x), heavy metals in water (Pb), and waste volume reduction.

In the second experiment, **seven indicators** were selected in order to assess the ranking of scenarios in terms of the impact on the environment. The selected indicators were: GHG emission (CO_2 Equivalent), acid gases emission (NO_x), smog precursors (PM), dioxins emission in air, heavy metals in water (Pb), organics in water (BOD), and waste volume reduction.

The third experiment examined the impact of **nine indicators** on scenarios ranking. The selected indicators were: GHG emission (CO_2 Equivalent), acid gases emission (SO_2, NO_x), smog precursors (PM), dioxins emission in air, heavy metals in water (Pb, Hg), organics in water (BOD), and waste volume reduction.

In the fourth experiment, **twelve indicators** were selected in order to assess the ranking of scenarios in terms of their impact on the environment. The selected indicators were: GHG emission (CO_2 Equivalent), acid gases emission (SO_2, NO_x), heavy metals in air (Pb), smog precursors (PM, VOCs), dioxins emission in air, heavy metals in water (Pb, Hg), organics in water (BOD), waste volume reduction, and energy consumption.

3.3. Indicators evaluation

Amounts of GHG, acid gases, smog precursors (PM, VOCs), heavy metals in air and water (Pb, Hg) and organics in air (dioxins) emitted to the atmosphere and water (BOD) were estimated using the data from the previous paper [5] in which the amount of gas emissions and heavy metals and organics remains in water was determined on the basis of the composition of waste using the Integrated Waste Management Model [17]. The amount of waste that remained after treatment for landfill disposal and energy consumption during waste treatment was also estimated by the Integrated Waste Management Model [17]. The Integrated Waste Management Model uses life cycle methodology to quantify the energy consumed and the emissions released from a user specified waste management system. The model has been structured so that it uses data specific to the user municipality to ensure applicability of the results and accuracy.

In assessing the emissions, this model takes into account the emissions from the point at which a material is discarded into the waste stream to the point at which it is either converted into a useful material or finally disposed. Emissions during transportation of waste, consumption of fossil fuels and electricity for the treatment of waste, and emissions during incineration are considered. The model does not evaluate the energy and emissions associated with the production of infrastructure (e.g. collection vehicles, waste management facilities, etc).

Table 3 Evaluation of environmental indicators

Indicators	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CO_2 Equivalent (t)	51,507	-85,273	17,830	-69,592
NO_x emission (t)	-2.5	-129.1	24.2	-111.6
SO_2 emission (t)	-3.4	-174.4	-6.5	-142.7
Pb emission in air (kg)	0.0	-2.6	47.1	-3.1
Smog precursors – PM (t)	17.5	-51.8	-1.7	-43.5
Smog precursors – VOCs (t)	7.8	-98.8	-1.2	-77.9
Dioxins emission in air (TEQ) (g)	0.001	0.0	0.048	0.006
Pb emission in water (kg)	0.81	-6.33	4.97	-42.52
Hg emission in water (kg)	0.0	0.072	-0.068	0.075
BOD emission in water (kg)	-6.0	19.043	277.0	26.354
Waste volume reduction (%)	4.65	80.59	90.48	95.69
Energy consumption (GJ)	-11,908	-1,042,126	-684,559	-1,043,542

4. Results and Discussion

Since the environmental indicators are by nature very diverse and expressed in different units, the probability or subjective evaluations, the multi-criteria decision analysis (MCDA) is the appropriate method for waste treatment scenario ranking in terms of their impact on the environment. The Analytic Hierarchy Process (AHP) is a multi-criteria decision making technique, quite often used to solve complex decision making problems in a variety of disciplines such as manufacturing industry, environmental management, waste management, power and energy industry, transportation industry, construction industry, etc. The AHP hierarchical structure allows decision makers to easily comprehend problems in terms of relevant criteria and sub-criteria. Additional criteria can be superimposed on the hierarchical structure. Furthermore, if necessary, it is possible to compare and prioritize criteria and sub-criteria in the AHP practice, and one can effectively compare optimal solutions based on this information. The decision procedure using the AHP method is made up of four steps: 1) defining the problem and determining the kind of knowledge sought; 2) structuring the decision hierarchy according to the goal of the decision – in the following order: the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) up to the lowest level (which is usually a set of the alternatives); 3) constructing a set of pair-wise comparison matrices. Each element of the matrix in the upper level is used to compare elements in the level immediately below; 4) using the priorities obtained from the comparisons to weigh the priorities in the neighboring level and doing this for every element. For each element in the level below its weighed values are added and its overall or global priority is obtained. This process of weighing and adding is continued until the final priorities of the alternatives at the bottom level are obtained. The AHP software Expert Choice 11 is employed for the analysis.

The results obtained in the four experiments after employing the procedure of multi-criteria analysis using the AHP method and pair-wise criteria, performed with the Expert Choice 11 software, are presented in the following subsections.

4.1. First experiment

The first experiment examined the effect of four indicators in ranking scenarios in terms of the impact on the environment: GHG emission (CO_2 Equivalent), acid gases emission (NO_x), heavy metals in water (Pb) and waste volume reduction. Following the pair-wise criteria, the criteria weight with respect to the goal was obtained.

Fig. 1 shows the ranking of scenarios after criteria (environmental indicators) weighting. According to the obtained results in the first experiment, it can be concluded that Scenario 4, which corresponds to zero waste to landfill scenario and includes recycling of waste (plastic, glass, paper and metal) and anaerobic digestion, has the best ranking in terms of environmental protection. The difference between the first and the second ranked scenario is 4%. According to the selected indicators, Scenario 1, the business as a usual scenario, ranked last.

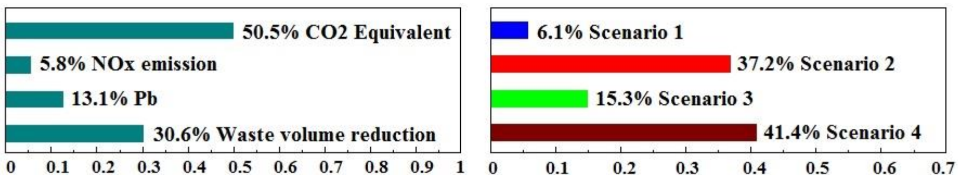

Fig. 1 Scenario ranking for evaluated indicators weight – first experiment

4.2. Second experiment

In order to increase the sensitivity of analysis in the second experiment, the number of indicators was increased from four to seven. Three indicators were added: smog precursors

(PM), dioxins emission in air and organics in water (BOD). The selected indicators were: GHG emission (CO_2 Equivalent), acid gases emission (NO_x), smog precursors (PM), dioxins emission in air, heavy metals in water (Pb), organics in water (BOD) and waste volume reduction.

Fig. 2 shows the ranking of scenarios after criteria weighting. According to the obtained results in this experiment, it can be concluded that Scenario 2 (composting organic and recycling inorganic waste) and Scenario 4 (anaerobic digestion of waste for the purpose of electricity generation) are equally ranked in terms of their impact on the environment. The reason is that Scenario 2 has a lower emission of dioxins in air and organics in water. According to the selected indicators, Scenario 3, which includes incineration with energy recovery, ranked last. Also, the difference between Scenario 1 and Scenario 3 is in the order of 1.4 %.

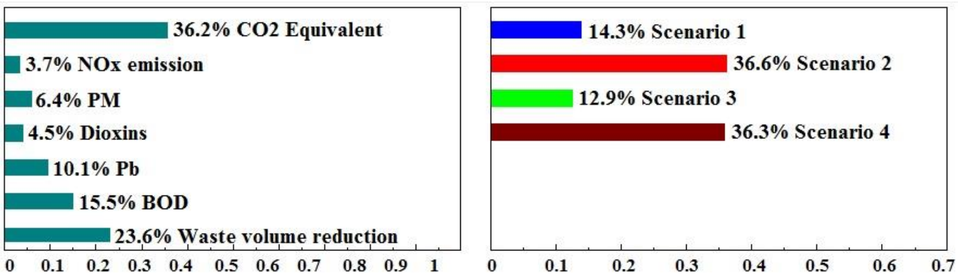

Fig. 2 Scenario ranking for evaluated indicators weight – second experiment

4.3. Third experiment

The third experiment examines the impact of the list of indicators expanded by two new indicators: SO_2 emission and heavy metal in water (Hg). The selected nine indicators were: GHG emission (CO_2 Equivalent), acid gases emission (SO_2, NO_x), smog precursors (PM), dioxins emission in air, heavy metals in water (Pb, Hg), organics in water (BOD) and waste volume reduction. Following the pair-wise criteria, the criteria weight with respect to the goal was obtained.

Fig. 3 shows the ranking of scenarios after the nine criteria (environmental indicators) weighting. According to the obtained results in this experiment, it can be concluded that Scenario 2 has the best ranking in terms of environmental protection. The reason is that Scenario 2 has a lower SO_2 emission in the air. According to the selected indicators, Scenario 1, which includes landfilling of waste, ranked last. With the increase in the number of indicators, the difference between Scenarios 2 and 4 increased, but the difference between Scenarios 1 and 3 decreased. This suggests that it is necessary to choose different indicators or increase their number in order to make a clearer difference between Scenarios 1 and 3.

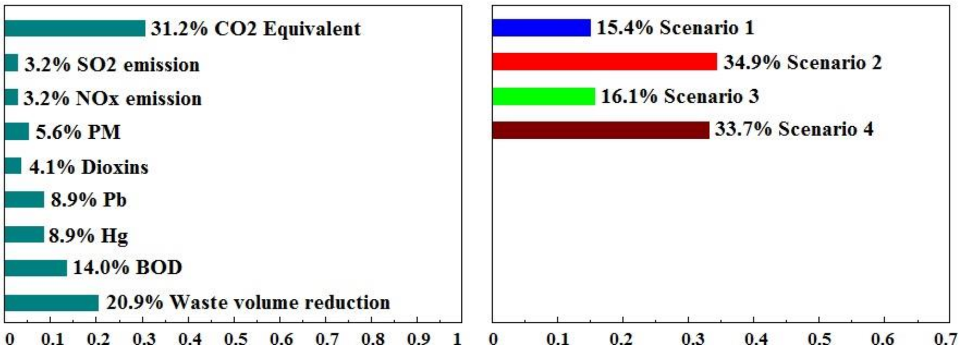

Fig. 3 Scenario ranking for evaluated indicators weight – third experiment

4.3. Fourth experiment

In the fourth experiment the impact of twelve indicators was examined. The list of indicators was expanded by three new indicators: smog precursors (VOCs) and heavy metal in air (Pb) and energy consumption. The selected twelve indicators were: GHG emission (CO_2 Equivalent), acid gases emission (SO_2, NO_x), heavy metals in air (Pb), smog precursors (PM, VOCs), dioxins emission in air, heavy metals in water (Pb, Hg), organics in water (BOD), waste volume reduction and energy consumption. Following the pair-wise criteria, the criteria weight with respect to the goal was obtained.

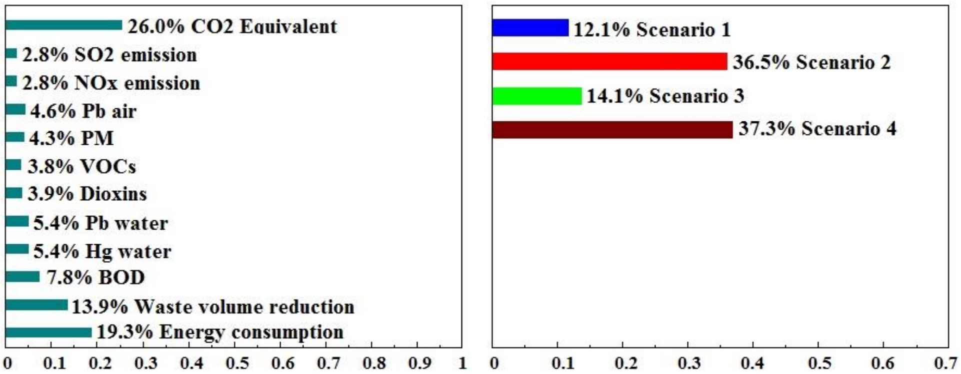

Fig. 4 Scenario ranking for evaluated indicators weight – fourth experiment

Fig. 4 shows the ranking of scenarios after criteria weighting. According to the obtained results in the fourth experiment, it can be concluded that Scenario 4 has the best ranking in terms of environmental protection, due to higher energy savings. According to the selected indicators, Scenario 1, which includes landfilling of waste, ranked last. By increasing the number of indicators, one can notice that the difference between Scenarios 2 and 4 increased by 0.8%. The difference is not entirely attributed to increasing the number of indicators. The diversification of the indicators to include other aspects, such as energy consumption, is also important, and needs to be taken into account. According to the data provided in Table 3, Scenario 4 has the lowest energy consumption of -1,043,542 GJ, while the energy consumption in Scenario 2 is -1,042,126 GJ.

5. CONCLUSION

The main problem in the analysis of environmental criteria is to determine the indicators that clearly and fully express the most important influential factors. To assess the impact of waste treatment on the environment, the multi-criteria analysis AHP method is applied. The selection of environmental indicators is performed as a result of the recognized priorities in environmental criteria and according to the OECD key environmental indicators.

The results obtained show that by increasing the number of environmental indicators there is a change in the ranking of scenarios in terms of impact on the environment. When selecting only four indicators, there is a small difference between Scenario 2 (recycling and composting) and Scenario 4 (anaerobic digestion) in favor of Scenario 4, although the selected indicators reflect the impact of waste treatment on air, water and soil. In case of selecting seven indicators, additionally considering PM and dioxins emissions in air and BOD in water, the difference between the waste treatment scenarios is even smaller. In this case the results show that Scenario 2 and Scenario 4 have the least negative impact on the environment. This result suggests that the number of indicators is insufficient to describe the complete impact of anaerobic processes on the environment; it is necessary to add to the consideration a variety of indicators that reflect the different impact of waste treatment on the environment, such as energy consumption, heavy metal (Pb) emission in the air, etc. If we consider nine indicators in order to assess the waste treatment on the environment, additionally considering SO_2 emissions in air and Hg in water, then there is a change in the scenario ranking. The best ranked scenario is Scenario 2. This result suggests that it is necessary to choose different indicators or increase their number in order to make a clearer difference between the scenarios. In the case of the fourth experiment which takes into consideration twelve indicators including energy consumption, the scenario ranking changes in favor of Scenario 4.

It can be concluded that by increasing the number of environmental indicators and considering a variety of indicators, it is possible to make a clearer difference between the waste treatments in terms of the impact on the environment. Also, it is necessary to make a careful selection of indicators and their number in order to properly assess the impact of waste treatment on the environment.

Based on the obtained results, the recommendations for the city of Niš in the selection of environmental indicators should include the consideration of a variety of indicators (12 indicators), which reflect different effects of the waste treatment on the environment. Because of the composition of waste in Niš, which consists of a substantial proportion of organic waste (min 45%), the indicators that take into account the effect of anaerobic digestion on the environment should be considered.

Further research should turn to determining a sufficient number of indicators and selecting the indicators based on the evaluation of the most important effects of the waste treatment on the environment and human health.

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