Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22468

117 (2018) 229–238
June

Treatment of the municipal landfill leachate including selection of the best management solution

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Received 3 January 2018; Accepted 3 May 3018

ABSTRACT

In the current work, the multicriteria decision analysis (MCDA) is used for the selection of the optimal variant of municipal leachate management. The investigated leachate comes from a municipal, non-hazardous and neutral waste landfill located close to the urban area in Southern Poland. Four different variants of leachate disposal were assumed, including the construction of a leachate treatment plant, discharge of leachate to the sewage system and recirculation of leachate in the landfill. The results of the MCDA revealed that the most advantageous solutions for leachate management (based on economic, environmental and social criteria) are variant I – integrated membrane system: coagulation – ultrafiltration and variant II – integrated membrane system: coagulation – nanofiltration. Variant I was chosen as the best technology for the disposal of leachates from municipal waste dumps, it already has sufficient environmental performance at lower costs than the variant II and comparable social acceptance scores. Discharge of leachate to the sewage system and treatment together with municipal wastewater in the municipal treatment plant (variant III) is not recommended. Recirculation of leachate in the landfill (variant IV) is indicated as the worst option, compared with other evaluated methods of leachate management.

Keywords: Multicriteria decision analysis (MCDA); Economic criteria; Environmental criteria; Social criteria; Waste management; Municipal landfill leachate; Leachate treatment

1. Introduction

In the transformation to the circular economy (CE) model, where the added value in products is kept for as long as possible and waste is eliminated, the changes in the waste management practices are required. According to a “zero waste programme for Europe” [1], in which it is stressed that sustainable economic growth is possible through transition to a CE model [2], a reduction of waste generation and safe recovery is assumed. Based on data published by Eurostat (2018) which is collecting data on Municipal Solid Waste (MSW), the amount of MSW generated per capita has been increased in European countries in last years. The detailed Polish statistics (2017) shows that the amount of MSW produced per capita has grown from 268 kg in 2014 to 283 kg in 2015. In 2015, municipal waste generation reached 10,864,000 ton and it was more then 5% higher comparing with 2014 [3]. As a consequence of the transition to the new model of economy promoted by European Union (EU), some changes in the treatment operations of municipal waste are observed, which is presented in Fig. 1. Despite the fact that the total amount of municipal waste increased in 2015, less waste is landfilled (12% of reduction) and more and more is processed and recovered in the recycling (32% of increase), composting or fermentation (52% of increase) processes. Incineration of waste was found to reduce waste by 8%

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Presented at the 13th Conference on Microcontaminants in Human Environment, 4–6 December 2017, Czestochowa, Poland.

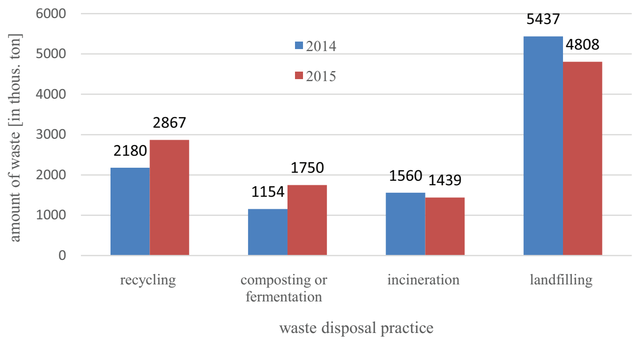

Fig. 1. Changes in the treatment operations of municipal waste collected in Poland in 2014–2015.
Source: Authors' own work based on a study carried out by Central Statistical Office [3].

in 2015. Hence it is indicated as the last possible solution in the waste hierarchy, just before safe landfilling.

In the EU countries, the landfilling rate (landfilled waste as share of generated waste) compared with municipal waste generation decreased from 64% in 1995 to 24% in 2016 (Eurostat 2018). Hovewer in many European countries, as Poland, a huge volume of waste still is directed to municipal landfills and dumping is the most frequently used method of municipal waste management [4]. One of the most important problem with their operation is the generation of leachate on dumps, which poses a potential threat to surface water, underground water and soil.

The arising municipal landfill leachate can be managed in few ways: treating by introducing leachate into the waste matrix – recirculating [5,6], directing (sewage transfer) to the local wastewater treatment plant (WWTP) [7,8], pretreating before direction to WWTP [3] or treating in leachate treatment plant located at landfill. Inappropriate disposal of leachate may have negative environmental, economic and ecological impacts [9]. Therefore, the choice of a specific solution of leachate management should be selected carefully by considering both regulations and constraints on other sources [10]. It requires the analysis of many aspects, including technical [11], environmental [12] and local conditions [13] and a careful economic assessment [14].

One of the tool supporting the choice of best management solution is the multicriteria decision analysis (MCDA), which is used to deal with the difficulties that decision makers encounter in handling large amounts of complex information [15]. In the MCDA, the principle is to divide the decision problems into more smaller understandable parts and further analysis of each part separately and then integrate the parts in a logical manner [9]. The objective of this study is to evaluate the possible scenarios for the leachate management on the municipal landfill with the use of the MCDA.

2. Management of the municipal leachate

The municipal landfill leachate is defined as the aqueous effluent formed as a consequence of rainwater percolation through waste, biochemical processes in waste's cells and the inherent water content of wastes themselves [16]. The leachate from the landfill is classified as industrial effluent [17,18] and it must be treated before being discharged to the receivers [18], both natural reservoirs [18] or sewers [17]. The physical and chemical properties of leachate discharged to receivers need to meet the requirement of Regulation the Minister of Environment [18]. The monitoring of the following indicator parameters in leachate is required for the municipall landfills [19]:

- pH value;
- electrolytic conductivity;
- total organic carbon (TOC);
- zinc (Zn), lead (Pb), cadmium (Cd), chromium (Cr + 6) and mercury (Hg);
- sum of polycyclic aromatic hydrocarbons (PAHs).

Management of leachate in landfills should be realized based on the actions that limit their amount. This can be achieved by:

- limiting the amount of leachate in the initial stage of operation of the landfill;
- limiting the amount of leachate through remediation of waste deposits and proper operation of the landfill.

According to the Regulation of the Minister of the Environment on landfills [19], the landfill should be equipped with drainage system of water taking into account the slope of the dump. The slope is also equipped with a drainage system allowing directing of leachate to the main system. Management of leachate should be taken into account:

- collection of leachate and its purification to a degree that allows it to be admitted to the treatment plant or discharged into water or land;
- collection of leachate in special tanks or direct discharge into the sewage system;
- possibility of using leachate generated on biodegradable waste dumps for technological purposes.

Due to the tightening restrictions on environmental protection requirements for ground and surface waters, high efficient treatment methods are required for landfill leachate treatment [20]. The following treatment methods are used:

- mechanical methods;
- physical methods (filtration, evaporation, stripping – gas stripping) [21];
- biological methods (aerobic, anaerobic) [22];
- chemical methods (neutralization, precipitation, oxidation, ozonation, Fenton reaction) [23,24];
- physicochemical methods (coagulation, adsorption, ion exchange, membrane processes) [25–27];
- integrated methods – the combination of a membrane process with other methods of treatment, for example, with biological treatment process (MBR – membrane bioreactor) [28,29], with coagulation/sorption [30].

In addition, in order to recycle the leachate and to reduce its amount [31], a recirculation of leachate into the landfill is also applied [32,33]. In Poland, this is one of the most commonly used methods of leachate disposal, apart from transferring it to the municipal sewage treatment plant [20]. It is also possible to concentrate the leachate and incinerate it in the incinerator; however, this method is not used in Poland. A choice of a suitable method of leachate treatment depends on its chemical composition and the susceptibility of the substrate to biological degradation. In the preliminary stage of leachate purification, physicochemical processes are usually used [34], and after – leachate is prepared for further biological treatment [35,36]. For the treatment of leachate from "young landfills" (up to 5 years of operation), it is necessary to use an integrated processes: biological and physico-chemical, and in the case of leachate from older objects, only physical-chemical processes are effective [37]. Literature data indicates that integration of biological and physico-chemical processes results in higher efficiency of purification. It has also been shown that systems with membrane processes are highly effective [38] and that purified effluents can be discharged into surface waters [39]. However, in many cases, the leachate with a high load of pollutions is directed to municipal wastewater treatment plants [40].

3. Materials and methods

This investigation presents the selection of the optimal variant of municipal leachate management with the use of multicriteria analysis. The possible variants have been presented below.

3.1. Determination of variants

In the first stage of the research, four variants in order to evaluate the possible scenarios of investment in leachate treatment plant were determined (Fig. 2).

The following variants were indicated:

Variant I – integrated membrane system: coagulation – ultrafiltration (UF),
Variant II – integrated membrane system: coagulation – nanofiltration (NF),
Variant III – discharge of leachate to the receiver – sewerage system,
Variant IV – recirculation of leachate in the landfill.

3.2. Characteristic of municipal leachate

The leachate described in the investigation comes from a municipal, non-hazardous and neutral waste landfill [19]. The municipal landfill is located close to the urban area in Southern Poland and classified as an old (in use for waste deposition since 1987). Currently, the landfill area is 470.4 ha, including two parts: main dump 128.4 ha and protection zone 342 ha. The leachate from that flows through the decomposing waste is collected by a network of drains at the bottom of the landfill [41]. The leachate is accumulated in special retention tank located at the plant with capacity of 3,300 m^3. Based on the technical and economic assumptions, absorbency of landfill was determined at 34 years, with inflow stream in amounts of 285,000 ton in 1987 to 385,000 ton in 2020. By maintaining the current stream flow of waste and implementation of waste management plant, time of the landfill exploitation can be extended to approximately 50 years [34].

In the present investigation, an example of stabilized landfill leachate studied in the previous works [34,42] were analyzed. Among the required indicators provided in Regulation the Minister of Environment [19],

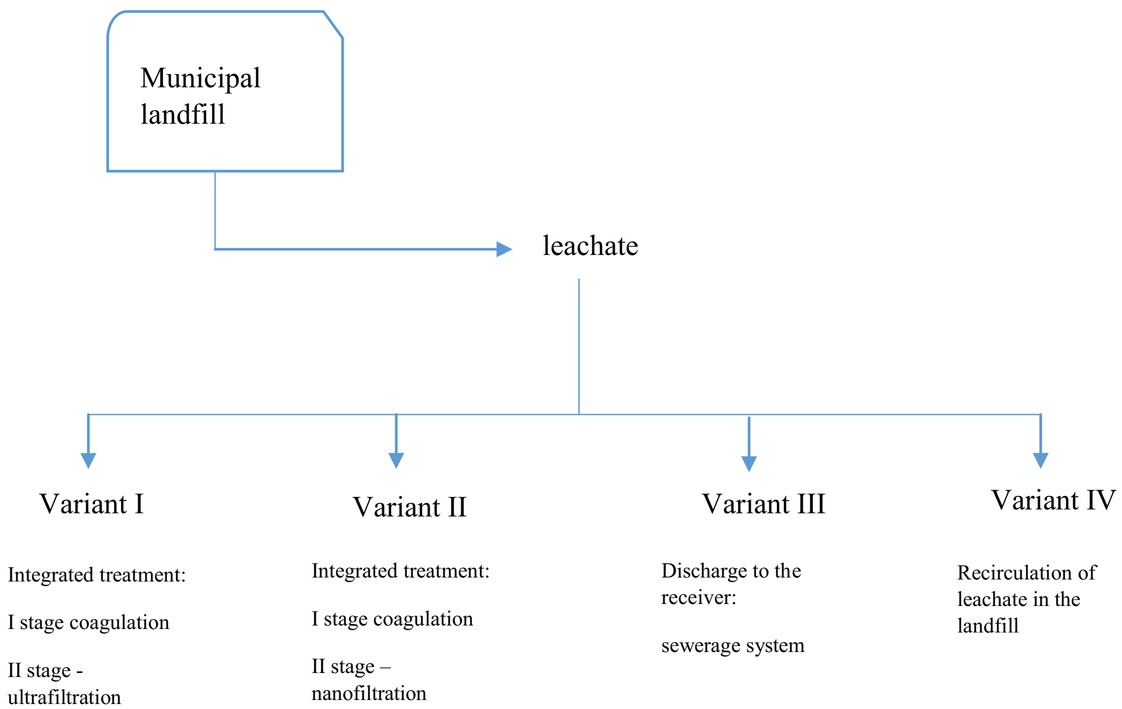

Fig. 2. Variants of the possible scenarios in leachate disposal practices.
Source: Authors' own work.

the concentration of selected parameters was determined, including [34]:

- pH value,
- TOC,
- sum of 16 PAHs listed by U.S. Environmental Protection Agency.

Moreover, the following parameters were evaluated:

- temperature,
- ammonium nitrogen (AN),
- chemical oxygen demand (COD),
- total carbon (TC),
- suspended soils (SS).

The leachate was identified in accordance with generally accepted methodologies [43] briefly described in a study by Smol et al. [34]. Technological treatment of leachate in Variant I and Variant II was carried out in two integrated systems, which were a combination of the pressure membrane techniques – ultrafiltration and nanofiltration with the initial treatment process – coagulation. The detailed description of the treatment technology and process parameters are presented in previous publications [34,42–44]. The results of the investigated parameters and limit values are presented in Table 1.

3.3. Experimental procedure

3.3.1. Multicriteria decision analysis – assumptions

MCDA is a mathematical method that can be used for selection of the best of the many considered options [14]. MCDA can be applied to assess value judgments of individual decision makers or multiple stakeholders [46]. There are usually various MCDA methods applied to the selection of the various treatment process of waste [47]. The common purpose of MCDA methods is to assess and choose among alternative scenarios based on multiple criteria using systematic analysis that overcomes the limitations of unstructured individual or group decision making [46].

There are several disposal treatment options for leachate, thus, choosing the optimal or the best available option usually involves decisions on the technology, location and capacity of the treatment plant [48]. An important factor for finding the best solution is to adopt a set of criteria (indicators) evaluating the assumed variants. The quantitatively presented criteria constitute the measure of fulfillment of the assumed objectives and goals that should be achieved with each described option. In the present work, economic, environmental and social criteria were determined. Moreover, the methods for estimating them need to be indicated. Among the groups of criteria, the following were distinguished:

- economic criteria – integrating goals describing the economic conditions for the establishment and operation of the system, including investment expenditures and operating costs of the system, as well as environmental fees borne by the landfill manager as a result of its exploitation; additionally, in this group the time possible to implement the technological relationship was taken into account, which will also have an impact on costs;
- ecological criteria – integrating goals describing the impact of the described technologies on the natural environment of the region, described as emissions as a result of exploitation. This group also includes odors and is estimated on a point scale because they are the most difficult to measure;
- social criteria – integrating social goals, the most difficult to quantify, depending on the adopted technical solutions, their impact on the natural environment, but also on the economic effects of the adopted technological solutions.

The decision matrix proposed for the evaluation of best leachate disposal method is shown in Table 2.

The decision task was solved with compromise programming method [49]. It allows to organize the options from the worst to the best using the concept of their arrangement, according to the distance from the so called "ideal point"

Table 1
Composition of the municipal landfill leachate and limit values related to the evaluated indicators [34,42]

Indicator	Raw municipal landfill leachate	Treated municipal landfill leachate		Indexes of sewage pollution which is directed to the natural receiver [18]	Indexes of sewage pollution which is directed to the sewers [45]
		Coagulation – ultrafiltration	Coagulation – nanofiltration		
pH	8.2	6.8	6.9	6.5–9.0	6.5–9.5
TOC (mg C/L)	364.9	129.2	120.9	30	*
16 PAHs (µg/L)	9.86	2.07	1.9	NS	200[a]
Temperature (°C)	18	19	19	35	35
AN (mg $N\text{-}NH_4^+$/L)	347.2	195.9	98.9	10	100[b] 200[c]
COD (mg O_2/L)	5078.9	794.1	633.1	125	*
TC (mg C/L)	517.6	131.2	101.7	NS	NS
SS (mg/L)	65.1	11.9	2.9	35	*

[a]Calculated based on carbon content.
[b]For wastewater discharged to the treatment plant for an area with a population >5,000.
[c]For wastewater discharged to the treatment plant for an area with a population ≤5,000.
*Values of indicators should be based on permissible load of these pollutants for individual treatment plant.
NS, not standardized.

Table 2
Decision matrix for selection of the best management solution for municipal leachate

Evaluation criteria		Evaluated management variants			
Description	Unit	Variant I – integrated membrane system: coagulation – ultrafiltration	Variant II – integrated membrane system: coagulation – nanofiltration	Variant III – discharge of leachate to the receiver – sewage system	Variant IV – recirculation of leachate in the landfill
		V1	V2	V3	V4
Economic					
Investment costs	1–10	7	10	5	9
Operating costs	1–10	7	10	1	9
Environmental sanctions	1–10	2	1	5	8
Implementation period	Year	3	3	5	8
Environmental					
pH	–	6.8	6.9	8.2	8.2
TOC	mg C/L	129.2	120.9	364.9	364.9
16 PAHs	µg/L	2.07	1.9	9.86	9.86
Temperature	°C	19	19	18	18
AN	mg $N\text{-}NH_4^+$/L	195.9	98.9	347.2	347.2
TC	mg C/L	794.1	633.1	5,078.9	5,078.9
SS	mg/L	131.2	101.7	517.6	517.6
Odors	1–10	2	2	3	10
Social					
Social acceptance	1–10	10	10	10	3
Impact on human health	1–10	10	10	7	4

with the coordinates $X'(x_1', x_2', ..., x_m')$. All coordinates of the ideal point are equal to a maximum value of the assumed normalization scale, that is, the point is always in the most advantageous position. Mathematical depiction of the searched distance of the analyzed option from an ideal point can be presented as follows:

$$L_\alpha(s_n) = \sum_{m=1}^{M} w_m^\alpha \cdot (x_m' - r_{NM}')^\alpha \tag{1}$$

The selection of the best option is done according to the following rule:

$$s_j = \bar{s} \Leftrightarrow L_\alpha(s_j) = \min L_\alpha(s_n); \qquad n = 1,2,...,N \tag{2}$$

where $L_\alpha(s_n)$ is the measure of divergence of a specific option s_n from the ideal point; $\bar{s}$ is the selected option; w_m is the weight coefficient for the criterion m; x_m' is the m coordinate of the ideal point; r_{NM}' is the normalized value of a criterion, M is the number of criteria, a is the exponent that measures the divergence of a criteria from the ideal point X'; in practice equal to 1, 2 and ∞.

The selection of the evaluation criterions criteria is usually the most difficult task during presented assessment [50–52]. In the current work, criteria are adopted as indicators for evaluation of the quality of municipal landfills leachate directed to various purification processes. Those indicators are the parameters of leachate disposal practices. Economic and social indicators, which were more difficult to assess, were estimated in a scale of 1–10 by a group of experts (five persons and one non-expert in the field), which were partially maximized and partially minimized (described in Table 2). Table 2 is a decision matrix, which is the thesis of the decision problem, the mathematical task, of finding the most advantageous solution for the disposal of leachate from municipal landfills, taking into account economic, ecological and social criteria.

4. Results and discussion

4.1. Multicriteria decision analysis and selection of the most favorable management solution

A comparison of management methods requires the prioritization of individual criteria to determine priorities for the participants in the decision-making process. Different priorities were chosen for determining the criterions significance (Table 3). A significance of 1 was assigned to each group of criteria in the first case, and in the other cases, the following criterion was assigned a significance of 2, whereas the other criteria were given a significance of 1 respectively, that is, the first criterion is twice as important as the others and so on. Environmental criteria were re-valued as two or five times more important than the criteria for evaluating the technology. The method also allows one to further prioritize the criteria by substituting α exponent in the formula.

Table 3
Ranking of technological solutions for leachate treatment of municipal landfills according to the weights of individual criteria

Importance of criteria	Ranking of the technologies		
	$\alpha = 1$	$\alpha = 2$	$\alpha = \infty$
1:1:1: 1:1:1: 1:1:1: 1:1:1: 1:1	V1* → V2* → V3 → V4	V1* → V2 → V3 → V4	V1* → V2 → V3 → V4
2:2:2: 2:1:1: 1:1:1: 1:1:1: 1:1	V1* → V2 → V3 → V4	V1* → V3 → V2 → V4	V1* → V3
5:5:5: 5:1:1: 1:1:1: 1:1:1: 1:1	V1* → V2 → V3 → V4	V1* → V3 → V2 → V4	V1* → V3
1:1:1: 1:2:2: 2:2:2: 2:2:2: 1:1	V2* →V1* → V3 → V4	V1* → V2* → V3 →V 4	No solution
1:1:1: 1:5:5: 5:5:5: 5:5:5: 1:1	V2* → V1 → V3 → V4	V2* → V1 → V3 → V4	No solution
1:1:1: 1:1:1: 1:1:1: 1:1:1: 2:2	V1* → V2* → V3 → V4	V1* → V2 → V3 → V4	V1* → V2 → V3 → V4
1:1:1: 1:1:1: 1:1:1: 1:1:1: 5:5	V1* ↔ V2* → V3 → V4	V1* → V2 → V3 → V4	V1* ↔V2* ↔ V3* ↔ V4*
2:2:2: 2:2:2: 2:2:2: 2:2:2: 1:1	V1* → V2 → V3 → V4	V1* → V2 → V3 → V4	No solution
5:5:5: 5:5:5: 5:5:5: 5:5:5: 1:1	V1* → V2 → V3 → V4	V1* → V2 → V3 → V4	No solution
2:2:2: 2:1:1: 1:1:1: 1:1:1: 2:2	V1* → V2 → V3 → V4	V1* → V3* → V2 → V4	V1* → V3
5:5:5: 5:1:1: 1:1:1: 1:1:1: 5:5	V1* → V2 → V3 → V4	V1* → V3 → V2 → V4	V1* → V3
1:1:1: 1:2:2: 2:2:2: 2:2:2: 2:2	V2* → V1* → V3 → V4	V1* → V2 → V3 → V4	No solution
1:1:1: 1:5:5: 5:5:5: 5:5:5: 5:5	V2* → V1 → V3 → V4	V2* → V1* → V3 → V4	No solution

That exponent makes it possible to further measure each deviation from the ideal point, pro rata to their size. The lower α value, the more important are large deviations from the ideal point of the strategy. Individual examples of calculations, taking into account various values of α coefficient are given in three columns of Table 3.

Table 3 shows the results of technological arrangements from the most favorable to the least favorable, taking into account the ecological, economic and social criteria and taking into account additional weighing with the α coefficient.

In calculations, restrictions were established as the so-called acceptability threshold calculated according to the formula:

$$S_n^{*)} = 0.1 \cdot L_\alpha \left(S_n\right)_{\min} \quad (3)$$

Acceptable strategies were labeled as * (Table 3) and were the solution to the decision-making task as the choice of a strategy that lies reasonably close to the ideal point. $_{\min}$

Summing up the results of the calculation, it was clarified that:

- 39 computational cases were carried out, assuming different weights of particular groups of criteria: economic, ecological and social as well as different coefficients α,
- considering all the computational scenarios 27 times as preferred, variant I – integrated membrane system: coagulation – ultrafiltration was chosen as the technology for leachate disposal, it already has sufficient environmental performance at lower costs than the variant II and comparable social acceptance scores,
- in six cases, variant II – integrated membrane system: coagulation – nanofiltration is chosen when higher weights are given to environmental assessment critics,
- in six cases, for $\alpha = \infty$, the decision-making task has no solution, that is, it lies infinitely far from the utopian point,
- variant IV – the recirculation of leachate in the landfill is always indicated as the worst solution, compared with the preceding ones in this research.

While the assessment of technology is finally described through the valuation and determination of the value of individual criteria, a question may arise as to whether all criteria are equally important. The previous chapter presents the results of a multi-criteria analysis, while the criteria were weighted by the authors of the analysis. Properly running decision-making process takes into account the interests of all groups interested in the form of the undertaking. Therefore, one should strive to develop uniform preferences where possible, so that all those interested are satisfied. The hierarchy of criteria validity is reflected by means of weighting factors. One way to determine them is to give weight to criteria by, for example, representatives of environmental organizations. In the prepared meetings at which technological solutions were consulted and presented, eight representatives of ecological organizations determined the weights for individual criteria. This study of the preferences of interested groups allowed for an open decision-making process. Table 4 presents the results of these analyses. The first row presents rankings of solutions for minimum values of weights accepted by an eight-person team from non-governmental organizations, the second includes the highest values of weights, and the third the average values.

As can be seen in Table 4, in the majority of calculation cases, variant V2 is the most advantageous one, followed by V1. Not much changes in the ranking previously presented by the authors of the analysis. Both are technologically comparable, from economic point of view the variant V2 is more expensive.

Table 4
Arranging technological solutions taking into account the weighting of criteria awarded by environmental organizations

Importance of criteria	Ranking of the technologies		
	$\alpha = 1$	$\alpha = 2$	$\alpha = \infty$
1:1:5:3:1:3:4:1:3:4:3:7:4:5	V2* → V1* → V3 → V4	V2* → V1* → V3 → V4	V1* → V2
3:4:10:9:5:9:10:5:8:9:7:10:9:9	V2* → V1* → V3 → V4	V1* → V2* → V3 → V4	No solution
1,5:2:8,6:5,4:4,2:8,7:9,3:3,1:6,7:7,1:5,5:9,8:7,4:8,4	V2* → V1* → V3 → V4	V2* → V1* → V3 → V4	No solution

For representatives of ecological organizations, the economic issues are less significant than environmental aspects, so the ecological criterias were indicated as the most important.

4.2. Discussion of the results

Nowdays, there are many management and technological solutions which can be used for wastewater (including leachate) treatment, and the selection of the most sustainable one among different processes is a hard task [53]. In order to solve various problems in environmental engineering, for example, during the selection of technology for wastewater treatment plant compatible with sustainable development [54], the use of the MCDA is recommended [55].

In the recent years, the changes in the disposal practices of municipal waste were observed. The most important of them is the fact that landfilling is declining and the recycling, composting or fermemntation processes are increasing. However, landfilling is still the most frequently used method of municipal waste management. Because landfill leachate creates a serious environmental problem, the landfill sites require sustainable leachate management options to be developed. From the four variants evaluated by the MCDA method, the following hierarchy (based on the ecological, economic and social criteria) was proposed:

Variant I > variant II > variant III > variant IV

Variant I was chossen as the best option in the selection of management method of leachate. These integrated membrane system, which includes two stages of leachate treatment – coagulation and UF should be considered first by the landfill operator. Variant II (coagulation – NF) should be taken into account just after variant I. In those both variants, the pre-treatment of leachate is coagulation, which has beed confirmed as a successful method for the removal of selected pollutants from stabilized and old landfill leachates [56]. Many studies have been presented on the examination of coagulation for the treatment of landfill leachates, including removal of COD in range of 27% [21] to 66% [58], removal of color up to 70% [57] or even 97% [58], TOC – 24% [57]. In the decision related to invest in this solution, the following issues should be included: to reach the best process optimization, to choose the most appropriate coagulant, to identify the optimum experimental conditions and pH effect [56]. Currently, coagulation is widely used as a pre-treatment [42], prior to biological or membrane step, or as a final polishing treatment step in order to remove non-biodegradable organic matter [56]. The combination of the membranes with other treatment methods is indicated as a highly effective solution [59], mainly microfiltration (MF), UF, NF and reverse osmosis (RO). MF is an effective treatment method for the removal of colloids and the suspended matter. It is considered as a pre-treatment for another membrane process since the elimination of polluting substances is never complete, for example, COD removal in the range of 10%–75% [28]. However, UF membranes can be successfully used in full-scale membrane bioreactor plants [60]. In the removal of pollutants from municipal leachate, nanofiltration shows better effects than ultrafiltration. The use of NF membrane creates excellent leachate treatment performance – removal of COD up to 80%–96% and color up to 98%–99.9% [61]. The integration of biological treatment with membrane techniques as UF and RO ensures such a level of treatment that the purified landfill leachate could be introduced into a natural water reservoir [28]. It needs to be pointed that one of the most important challenge is to keep the hydraulic performance of the used membranes. A wide spectrum of pollutants in leachate may contribute to fouling on membrane surface, including dissolved organic and inorganic substances, colloidal and suspended particles [38]. Successful application of membrane technology requires efficient control of membrane fouling [62].

In the recent years, a common solution was to treat the leachate together with municipal wastewater in the municipal treatment plant. It was preferred according to easy maintenance and low operating costs [62]. Variant III represents this management method of leachate. Brennan et al. [8] indicate that although co-treatment of landfill leachate at municpal wastewater treatment plant may be appropriate in some circumstances, the inherent variability in leachate composition and treatability necessitates a conservative approach [8]. This option has been also increasingly questioned due to the presence of organic inhibitory compounds with low biodegradability and heavy metals that may reduce treatment efficiency in treatment plant. It could also casuse an increase in the effluent concentrations from municipal wastewater treatment plant [62]. Moreover, it could create some additional costs related to higher environmental fees for the introduction of polluted effluent in the sewage system.

Variant IV is indicated as the worst option in the management of municipal leachate. Recirculation of leachate (variant IV) offers potential advantages as a reduction of the volume of liquid by surface evaporation, and reduction of the strength of leachate by crude anaerobic treatment within the landfill. Increasing the moisture content of the fill is also reported to give rise to a more rapid stabilization of solid waste, and to enhance gas (methane) production. However, the recirculation by itself cannot provide a lasting solution for leachate management. The direct discharge of leachate could result in ecotoxicity and human toxicity via water contaminated by heavy metals in effluent. Constant and careful control is required and, in particular, it is necessary to consider the hydrology of a landfill and how this is affected by use of (final and intermediate) cover material [63].

It needs to be mentioned that exploring an effective and economic treatment method for the leachate is necessary for many municipal waste management plants [64]. The investments in such environmental protection projects register an increasing trend in waste sector [65]. Studying their efficiency provides insights for further developing of new investments. The investments efficiency issue is very complex, based on a large number of generated effects. It covers three distinctive concepts: economic, environmental (ecological) and social efficiency of investments [66]. The choice of process or combination of processes for a given leachate should be selected individually for each case using the criteria presented in Table 2. Moreover, the following issues should be also taken into account: type and concentration of substances in leachates, requirements for purified leachate, amount of leachate generated (now and in the future), possibility of recovery/disposal of residues, available type of energy, economic opportunities of management unit and local conditions. Based on the presented criteria, the investment in the leachate treatment plant with integrated membrene system is recommended. It requires financial inputs [10] at the stage of building and operating of plant, however, it creates environmental [67] and social [68] added values in the long term. There are many advantages of membrane techniques as low dependence on the type and concentration of pollutants, high efficiency, high degree of automation, ease of extension, small area needed for construction, no emissions to air (closed systems), an ability to achieve initial parameters after downtime, repairs, cleaning of membrane surface. Disadvantages of membrane techniques include high investment costs, sensitivity of the membrane to thermal, chemical and mechanical interactions and necessity for treatment and disposal of the resulting concentrate and sludge [69].

Leachate management is a difficult problem in the exploitation of landfill waste. This is one of the most importatnt reason for avoiding waste generation – do not buy unnecessary items, pay attention to the packaging, use re-purchased items, according to CE assumptions [70]. An appropriate selection of investment projects is significant challenge in municipal waste plant. An incentive to implement such projects is fact that building of leachate treatment plant could be supported by significant resources for the financing of investment and ecological activities in European countries [71]. In recent years, dynamic growth of expenditure on environmental protection has been observed in EU. Initially, the criteria for the granting of financial assistance were very lax, but over time more and more attention has been paid to the selection of investment projects which fulfil all economic, social and ecological criteria [72].

5. Conclusions

Municipal landfill leachate creates one of the most difficult environmental and nuisance impacts. It must be subjected to disposal processes before being discharged into the receivers, both natural reservoirs or sewers.

In the current work, the possibility of using MCDA to select the most advantageous method of leachate management was proposed. The four variants of leachate management on landfill were evaluated by the MCDA method. Variant I and variant II included the integrated membrane system: coagulation – UF/NF respectively, variant III included discharge of leachate to the sewage system and variant IV – recirculation of leachate.

The analysis showed that the most advantageous is the use of the integrated membrane system: coagulation – UF (variant I), with a high purification effect at relatively low cost and social acceptance. The system combining coagulation with NF (variant II) was evaluated on a comparable level to variant I. The treatment of the leachate together with municipal wastewater in the municipal treatment plant (variant III) is not recommended and recirculation of leachate in the landfill (variant IV) is always indicated as the worst solution, compared with other evaluated methods of leachate management.

The analysis can be used for similar computational cases, using local solutions and data.

Acknowledgment

The research was funded by the statutory research of MEERI PAS.

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