

## METHODOLOGY OF STRATEGIC ENVIRONMENTAL ASSESSMENT IN CROATIAN RADIOACTIVE MANAGEMENT SECTOR

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Considering co-ownership in Nuclear Power Plant Krško, Republic of Croatia has a responsibility towards radioactive waste disposal after its decommission. Besides that, as a member of European Union, Republic of Croatia should follow the rules prescribed by International Atomic Energy Agency (IAEA) and should propose the most appropriate site for disposal of Low and Intermediated radioactive waste (LILW). The results of technical reports and expert opinion regarding proposal of possible sites for radioactive waste disposal has raised certain controversies and public dispute. As a possible contribution to solution of this issue, a multi-criteria decision-making approach (MCDM) was applied in this work, relying on Croatian strategic framework and guidelines for sustainable development. The most appropriate site was found to be Trgovska gora (score of multi-criteria analysis is 0.9400). Furthermore, possible environmental impacts of the project concerning permanent radioactive waste underground repository are discussed, following the guidelines of the Environmental Impact assessment (EIA) scoping and considering the existing environment of the selected site.

**Key words:** strategic environmental assessment, environmental impact assessment, low and medium-level radioactive waste disposal, multi-criteria decision-making.

**Metodologija strateške procjene utjecaja na okoliš pri upravljanju radioaktivnim otpadom u Hrvatskoj.** S obzirom na suvlasništvo u Nuklearnoj elektrani Krško, Republika Hrvatska je suodgovorna i za zbrinjavanje jednog dijela radioaktivnog otpada nakon zatvaranja elektrane. Osim toga, kao članica Europske unije, Republika Hrvatska podliježe pravilima Međunarodne agencije za atomsku energiju (IAEA) te u skladu s tim treba izabrati najprikladnije mjesto za odlaganje nisko i srednje radioaktivnog otpada (NSRAO). Rezultati tehničkih izvješća i stručnih mišljenja vezanih uz izbor mogućih lokacija odlagališta radioaktivnog otpada, dočekana su uz veliki otpor javnosti. Kao mogući doprinos rješenju ove problematike, u ovom je radu uz primjenu pristupa višekriterijskog odlučivanja (MCDM), a uz oslanac na Strateški okvir Republike Hrvatske i smjernice održivog razvoja, utvrđeno da je najprikladnija lokacija za odlaganje NSRAO Trgovska gora (rezultat višekriterijske analize je 0,9400). Nadalje, izloženi su mogući utjecaji na okoliš predviđenog zahvata koji podrazumijeva izgradnju podzemnog silosa, prema smjernicama procjene utjecaja na okoliš (PUO), uzimajući u obzir postojeće stanje okoliša i obilježja odabrane lokacije.

**Ključne riječi:** Strateška procjena utjecaja na okoliš, procjena utjecaja na okoliš, odlagališta nisko i srednje radioaktivnog otpada, višekriterijsko odlučivanje.

## INTRODUCTION

Radioactive waste (RW) is generated in a number of different kinds of facilities and it may arise in a wide range of concentrations of radionuclides and in a variety of physical and chemical forms. These differences result in a wide variety of alternatives for processing waste and for short term or long term storage prior to disposal. Likewise, there are various alternatives for the safe disposal of waste, ranging from near surface to geological disposal [1]. RW must be disposed in a way to avoid any environmental contamination or unacceptable radiation [2]. Waste disposal facilities, which are built for permanent repository of RW, meet prescribed general standards of radiation protection and specific security requirements. Those facilities are used for insulation of RW from human and environment. The disposal site is usually designed to evade a continuous and active monitoring after closing its content [3,4]. The main reason for such a policy is the guiding ethical principle; future generations should not carry unnecessary burdens and responsibilities. However, in order to increase the safety and security, and help the local community to accept the permanent RW repository, it is necessary to plan various forms of institutional control of landfill in the initial period when the radioactivity is the highest. The nuclear waste disposal facilities are built or planned depending on the waste quantity and radioactivity level, as well as of the characteristic of available disposal sites. A project concerning RW disposal must meet national regulations, must respect international agreements, strongly depending on social, political and economic circumstances [5-7].

International Atomic Energy Agency (IAEA) has described various aspects of possible radioactive waste site investigation techniques and assessment for all 162

member countries. The IAEA inputs has dealt with all different phases and aspects of the investigation of the suitability of a site for a waste repository, starting from general and regional investigations, and proceeding via comprehensive site-specific detailed geo-scientific investigation to site confirmation studies and final assessment. Republic of Croatia and its neighbouring countries as members of IAEA should follow the Agency prescriptions for selection of the site for disposal of radioactive waste [1, 4-6].

Various schemes have evolved for classifying radioactive waste according to the physical, chemical and radiological properties that are of relevance to particular facilities [8]. The waste of concern from NEK was classified as the Low and Intermediate Level Waste (LILW), containing radionuclides with half-life less than 30 years [9,10]. The disposal facilities for LILW are usually built at the ground level or at depths of up to several tens of meters, whereas a major contribution to the insulation from the environment can be provided with appropriate procedures of waste processing and packaging [4,11]. However, according to basic safety standards, waste in this class requires disposal at greater depths than near surface disposal, of the order of tens of metres to hundreds of meters [1]. Circumstantially, there is no need to dispose waste into deep and exceptionally stable geological layers [12].

Building a LILW disposal facility in the Republic of Croatia has already been considered as a possibility [9,13]. The need for the construction of such sites appeared at the time when Croatia and Republic of Slovenia planned to build two joint nuclear power plants. However, while Slovenia built the Krško Nuclear Power Plant (NEK), Croatia abandoned the construction of the second one on its territory. Regardless of the

abandonment, co-ownership of the NEK continued to imply responsibility of Croatia for the waste disposal. It is estimated that during the NEK working cycle approximately 7000 m<sup>3</sup> of LILW is generated and about 10000 m<sup>3</sup> of waste from decommissioning of nuclear installations will remain [14]. Republic of Croatia is responsible for the half of that amount, i.e. 3500 m<sup>3</sup> of LILW generated during the NEK operation cycle and additional 5000 m<sup>3</sup> formed in decommissioning procedure after shutting down of the plant. In addition, smaller amounts of LLW and LILW made to date in Croatia originate from different types of applications, such as medicine, industry, agriculture and research institutes. Additionally, spent sources of ionizing smoke detectors (now about 60000 are used in Croatia) and the radioactive lightning rods (370 still in use) should be considered as well. Currently, special facilities (Ruđer Bošković Institute and Institute for Medical Research and Occupational Health in Zagreb) are used to store RW temporarily. About 50 m<sup>3</sup> of used sources of ionizing radiation and other used radioactive substances (total activity is approximately 1.4 TBq) are stored at those research institutes already [15].

To address the issue of LILW disposal seriously and responsibly, it is essential to store it according to basic safety standards. A well-built LILW repository in the most appropriate location is of the paramount importance. Although, according to the existing regulations, the best disposal locations must be defined through the procedure of Strategic environmental assessment (SEA), according to the SEA Directive 2001/42/EC, and the procedure of the best technology selection can be performed through the Environmental impact assessment (EIA). From environmental point of view, both procedures are based on similar or same methods and methodologies. Furthermore, a

certain elements of Environmental impact assessment (EIA) were considered in this work taking into account the results of several studies already performed regarding the LILW repository in Croatia and Slovenia [13,14,16].

EIA is the evaluation of the effects likely to arise from a major project (or other action) significantly affecting the environment. It is a systematic process for considering possible impacts prior to a decision being taken on whether or not a proposal should be given approval to proceed. EIA requires, inter alia, the publication of an EIA report describing the likely significant impacts in detail. Consultation and public participation are integral to this evaluation. EIA is thus an anticipatory, participatory environmental management tool. Environment impact assessment is based on European Council Directive 85/337/EEC from June 27, 1985; substantially amended several times [17]. European Union policy on the environment is based on the precautionary principle and on the principles of preventive actions; the environmental damage should be reflected at source, meaning that the effects on the environment should be taken in consideration at the earliest possible stage in all the technical planning and decision-making process [18]. The main obligations of the project developers are that the principles of the assessment of the environmental effect are harmonized, especially on the projects that should be subject to assessment (Annex I, Directive 85/337/EEC). According to the pre-accession treaty, Croatia was obligated to obey the same rules as Member States of European Union. The Regulation on Environmental Impact Assessment, issued by The Government of the Republic of Croatia [19] is fully compatible with the EU Directive. In this work, only expected environmental impacts are discussed.

The novelty of presented approach assumes the use of multi-criteria decision making for the selection of the most appropriate location in Croatia. National strategies regarding tourism, socio-economic development and water resources were taken into account during site selection process

[20-23]. The main hypothesis is that the existence of LILW repository near tourist locations can significantly decrease the overall appeal of those areas, consequently resulting with the Croatian economic breakdown.

## METHODOLOGY

### Data collection

In this study, we will show the possible locations for LILW disposal in Croatia based on a detailed analysis and criteria prescribed by the authorities [13,24] and related arguments [25]. In addition to the selection procedure of the most appropriate site, this study also presents an

overview of expected environmental impacts of LILW repository. As a base for this research many data were collected from available literature and official reports: analysis of appropriate sites for disposal, quantities of LILW waste from NEK and suggested technologies for disposal.

### *Review of possible disposal locations*

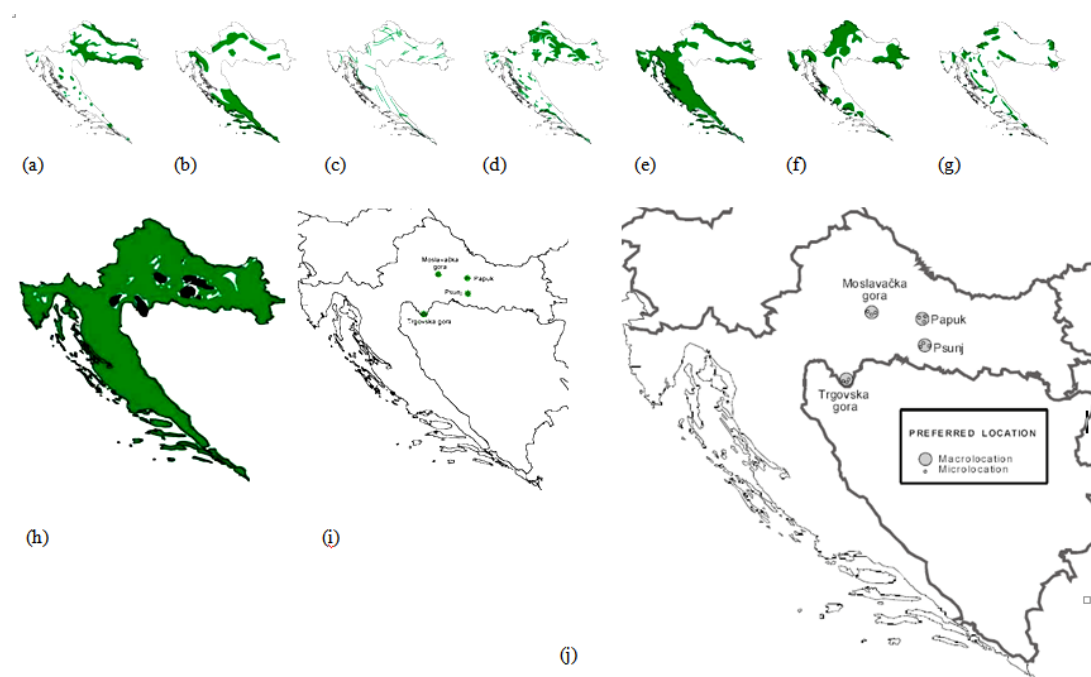
The site selection procedure begins with evaluating the entire Croatian area. In the initial stage of further research, using the preliminary criteria (exclusionary screening), territories that do not meet the basic requirements for LILW repository are rejected. If the area has features that could reflect in a way to jeopardize the security of the environment and human health, the area is rejected as unacceptable [13,24]. Fig. 1. presents a review of rejected areas according to the preliminary criteria. Safety of flooding is the first listed criteria (Fig. 1a.); all natural floodplain areas and those that may be at risk of flooding are rejected. A second criterion was seismotectonics (Fig. 1b.); it is necessary to reject all areas that are affected by the strong earthquake, with expected minimum earthquake intensity of IX MCS. Furthermore, neotectonics is another criterion (Fig. 1c.). Areas that are in nominated active fault zone are rejected. In the neotectonic active areas and near the active fault shifts and

rocks cracking that can cause buildings damage is highly possible. Lithological composition, geotechnical and geomorphological features are among the most important criteria for the landfill space evaluation for RW accommodation (Fig. 1d.). Best parent rocks are clay of Upper Pliocene and Quaternary and Neogene marls (so-called "Abichi deposits"). Therefore, areas that do not meet these requirements, or areas with increased erosion caused by lithological composition or dynamic relief, which are made up of unstable rock in natural conditions and/or during construction activities are rejected. Hydrologic conditions are further evaluated (Fig. 1e.). Groundwater is the most likely transmission medium of radionuclides from the disposal sites into the biosphere, therefore, it is very important to know the hydrogeological conditions. Drinking water sources in the protection areas [26,27] as well as areas that show a high risk of contamination of the aquifer are rejected.

Since radionuclides can enter the environment primarily by groundwater, RW repository must be located in areas with no aquifer or clearly limited isolated aquifers. Thus, knowledge of the groundwater runoff mechanism in the wider area of the landfill is very important for the environment safety. Rejected areas are all areas of karst in Croatia (Fig. 1e.). Demographics, i.e. population density is another significant criterion for disposal site selection (Fig. 1f.). Areas with the cumulative density of more than 80 inhabitants per sq km (average density Croatian) in the radius of 20 km from the potential site are rejected. Other exclusionary criteria are presented in Fig. 1g. According to the requirements of National Defence, special purpose areas and their buffer zones are rejected. Areas in present or future exploitation zones (e.g. ores, minerals, gas, oil, coal, etc.) are also

rejected. The exploitation of useful material, which is found in the earth's crust, can adversely affect the safety of the landfill. Due to the requirements for protection of natural heritage, National Parks [28], areas with recognized environmentally sensitive parts of the plant and animal world and other important nature reserves are rejected. Areas that are specified in the World Heritage List and cultural heritage areas that are extremely important to the community are excluded from site selection.

Favourable areas for LILW repository are obtained by excluding the "overlapping" Croatian territories that have been rejected by preliminary criteria (Fig. 1h). Finally, four areas were determined (Fig. 1i and j): Trgovska gora (TG), Moslavačka gora (MG), Papuk (P1) i Psunj (P2). Certain characteristics of these locations are given in Table 1 [25].



**Figure 1.** (a-g) Exclusionary screening according to given criteria (*green areas* are rejected) and (h,i) available sites - *black areas* (summarized from Schaller, 1997); (j) detailed preferred sites selected for final repository (adopted from Matanić and Lebegner, 1999)

**Slika 1.** (a-g) Odabir lokacija prema zadanim kriterijima (zelenom bojom su označene odbačene lokacije) i (h,i) pogodne lokacije - crna boja (prema Schalleru, 1997); (j) detaljniji prikaz pogodnih lokacija odabranih za konačno odlagalište (prema Mataniću i Lebegneru, 1999)



**Table 1.** Comparison of possible sites for RW disposal (according to Schaller, 1997; Matanić and Lebegner, 1999; otherwise indicated)

**Tablica 1.** Usporedba mogućih lokacija za odlaganje RO (prema: Schaller, 1997; Matanić i Lebegner, 1999; posebno naznačeno)

<i>Characteristics</i>	Papuk (P1)	Psunj (P2)	Moslavačka Gora (MG)	Trgovska Gora (TG)
Altitude (m)	450	670	190	320
Lithology composition	granite	amphibolite	granite, gneiss	sandstone, clay, shale
Permeability ( $\text{ms}^{-1}$ )	$10^{-11} - 10^{-15}$	$3 \times 10^{-17}$	$10^{-11} - 10^{-13}$	$7.8 \times 10^{-21} - 6 \times 10^{-19}$
Porosity (%)	0.74–6.50	1.94–8.66	0.74–6.50	2.90–10.20
Slope processes	Very weak erosion	Weak erosion	Very weak erosion	Weak erosion
Average slope (%)*	9.6	11.2	3.0	9.9
Vertical relief dissection ( $\text{m km}^{-2}$ )	>300	>100	>100	>300
Max. earthquakes (MCS)	VIII	VII – VIII	VII – VIII	VII – VIII
Distance from active fault (km)	25	12	1-5	1-2
Quantity of precipitation in one year (mm)**	1100	1150	910	977
Exploitation	forestry, recreation, entertainment	TV-transmitter, recreation	hunting, forestry, recreation	N/A

\* Geomorphometric properties are depicted in Fig 4c

\*\* Data for 1999 according to Meteorological and Hydrological Service

### *Quantities of LILW*

Nuclear decommissioning plan for NEK was made jointly by the Croatian and Slovenian agencies (APO and ARAO) in 2004. Total amount of LILW (throughout NEK life, span and amount that will arise from decommissioning) was estimated on amounts of LILW produced until 2004 and projection of waste growth [14]. Unpredictable and/or accidental events that could enlarge amount of waste were not

included. Upon decommissioning, the total amount of LILW was approximated to  $17.600 \text{ m}^3$ . It was also estimated that around 1% of waste are long-living radionuclides ( $\sim 200 \text{ m}^3$ ). However, only LILW with short half-life are considered for disposal, while long-living nuclides will be kept with spent nuclear fuels (SNF) on NEK location until necessary [14].

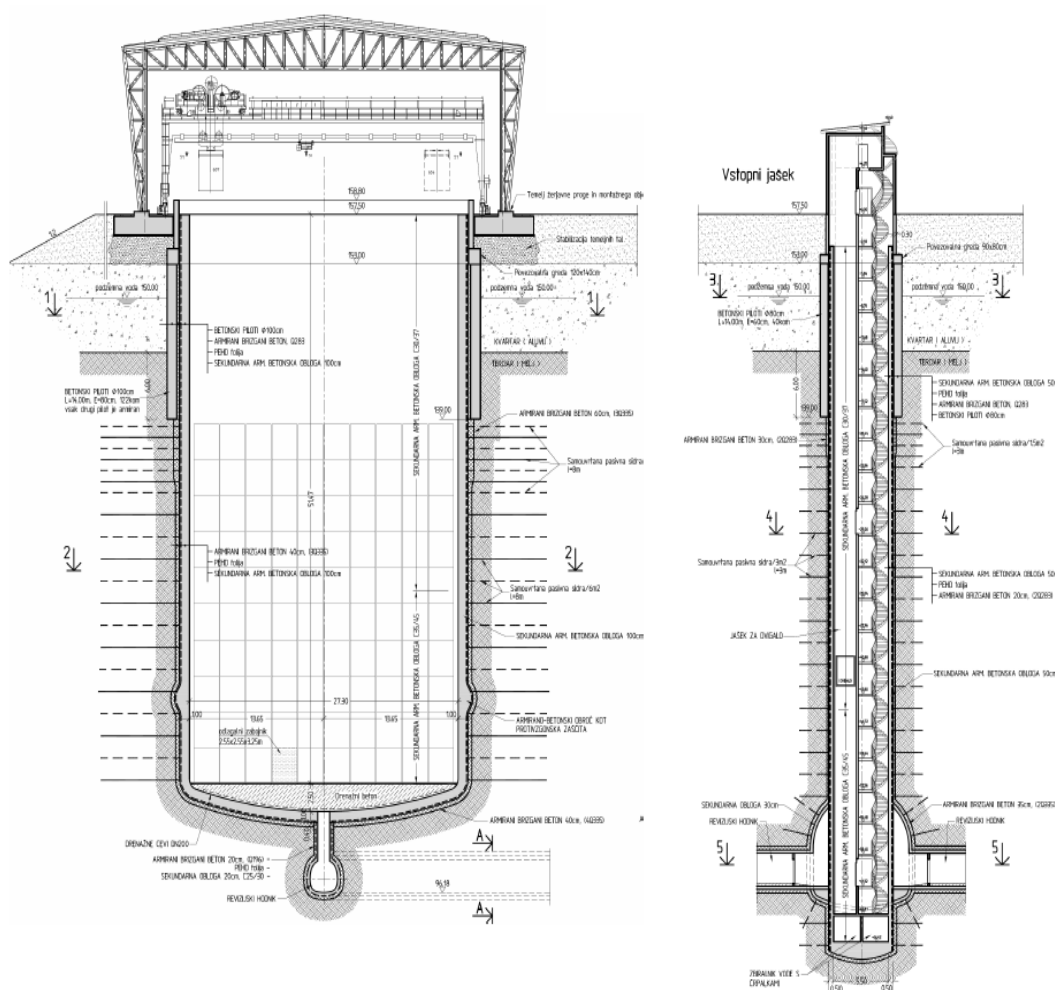
### *Suggested technical solution*

According to the nuclear decommissioning plan for NEK, underground disposal site is suggested. This type of disposal site consists from underground part for the transport and disposal of waste, and surface facilities (few thousands of  $\text{m}^2$ ) for

admission, procession and preparation of waste, and some other activities [14]. Underground part consists of access pits and pits for disposal. Disposal pits end in access pit that connects underground part with the surface [14,29,30]. Disposal pits

are divided into partitions where the waste is permanently stored and space between them is filled with concrete. Most distant pit is first one to be filled and when it is full, the concrete lid is put on the waste. After the whole pit is filled, transport equipment is removed and pit is additionally filled with concrete. A proposed construction alternative for silos is depicted in Fig. 2. When all disposal pits are full, only thing left is to fill the drainage pipes what is done just before the disposal site stops being actively

supervised. Main goal of disposal site is making sure no nuclides end up in environment, and that is ensured by using different types of manmade and natural barriers. A system of drainage and collection pipes for clean water and water that comes from the environment must be provided. Disposal site is a complex technological unit, including all infrastructure and systems needed for safe and self-contained work.



**Figure 2.** Schematics of silos (left) and access pit (right) for RW disposal in Slovenia (suggested by Boštjan Duhovnik; as presented to ICJT – Slovenian Nuclear Training Centre, March 30, 2010)

**Slika 2.** Shematski prikaz silosa (lijevo) i prilaznog rova (desno) za odlaganje RO u Sloveniji (prema Boštjanu Duhovniku; predstavljeno u ICJT – Slovenski nuklearni centar za obuku, 30. ožujak 2010)

Preliminary analysis indicates that disposal silos which would contain all the waste from NEK (17.600 m<sup>3</sup>) should be 90 m deep and have the diameter of 22 m. Transportation from the NEK to the site would be made by road, and the disposal

### EIA elements

EIA is a multi-step process. Among the required steps, the following is recognized within this work: screening, scoping and the preparation of the environmental report. Regarding the *screening*, any project concerning nuclear waste disposal is a subject of Annex I (European Council Directive 85/337/EEC), and the full EIA process is required for such a project. *Scoping* is the process by which information required for the environmental report is

would be made by elevators. Minimal height of the layer put on the wasteland depends on the type of the soil. Beside prevention methods, site needs to have safe measurements in the build period and period after closing.

determined, pointing out the crucial environmental aspects of the project. In this work the significant elements of scoping are presented. We identify, describe and assess the direct and indirect effects of the LILW repository on: human beings, fauna and flora, soil, water, air, climate and natural heritage. The facts given throughout this work could serve as a preparation for some future environmental reports.

### MULTI-CRITERIA DECISION MAKING APPROACH

The typical MCDM problem deals with the evaluation of a set of alternatives in terms of a set of decision criteria. Several MCDM are widely used; e.g., the weighted sum model (WSM), and the analytic hierarchy process (or AHP) [31] that has become increasingly popular recently. There are three steps in utilizing any decision-making technique involving numerical analysis of alternatives: (i) Determining the relevant criteria and alternatives, (ii) Attaching numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria, (iii) Processing the numerical values to determine a ranking of each alternative.

The weighted sum model (or WSM) is probably the most commonly used approach. If there are  $M$  alternatives and  $N$  criteria then, the best alternative is the one that satisfies (in the maximization case) the following expression [32]:

$$A_{WSM}^* = \max_i \sum_{j=1}^N q_{ij} w_j \quad \text{for } i = 1, 2, 3, \dots, n \quad (1)$$

where:  $A_{WSM}^*$  is the WSM score of the best alternative,  $n$  is the number of decision criteria,  $q_{ij}$  is the actual value of the  $i$ -th alternative in terms of the  $j$ -th criterion, and  $W_j$  is the weight of importance of the  $j$ -th criterion.

The analytic hierarchy process (or AHP) [33,34] is based on decomposing a complex MCDM problem into a system of hierarchies. The final step in the AHP deals with the structure of an  $m \times n$  matrix (where  $m$  is the number of alternatives and  $n$  is the number of criteria). This matrix is constructed by using the relative importance of the alternatives in terms of each criterion. The vector for each  $i$  is the principal eigenvector of an  $N \times N$  reciprocal matrix which is determined by pairwise



comparisons of the impact of the  $M$  alternatives on the  $i$ -th criterion. According to AHP the best alternative (in the maximization case) is indicated by the similar relationship as in WSM (Eq. (1)).

Considering  $n$  elements to be compared,  $C_1$  to  $C_n$  and denote the relative "weight" (or significance) of  $C_i$  with respect to  $C_j$  by  $a_{ij}$  and form a square matrix  $A = (a_{ij})$  of order  $n$  with the constraints that  $a_{ij} = 1/a_{ji}$ , for  $i \neq j$ , and  $a_{ii} = 1$ , all  $i$ . Such a matrix is a reciprocal matrix. For such a matrix,  $\omega$  is an eigenvector (of order  $n$ ) and  $\lambda$  is an eigenvalue ( $A\omega = \lambda\omega$ ). For a consistent matrix,  $\lambda = n$ . For matrices involving human judgment, the  $\omega$  vector satisfies the equation  $A\omega = \lambda_{\max}\omega$  and  $\lambda_{\max} \geq n$ . The difference, if any, between  $\lambda_{\max}$  and  $n$  is an indication of the inconsistency of the judgments. If  $\lambda_{\max} = n$  then the judgments have turned out to be consistent. Finally, a Consistency Index (CI) can be calculated from Eq. (2).

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (2)$$

That needs to be assessed against judgments made completely at random. In Saaty's book

large samples of random matrices of increasing order and the Consistency Indices of those matrices are calculated [35]. A true Consistency Ratio (CR) is calculated by dividing the Consistency Index for the set of judgments by the index for the corresponding random matrix.

In this study order of the matrix is  $n = 8$ , and the corresponding index of random matrix is 1.41. CR is then calculated by Eq. (3).

$$CR = CI / 1.41 \quad (3)$$

According to Saaty, if CR exceeds 0.1 the set of judgments may be too inconsistent to be reliable. A CR of 0 means that the judgments are perfectly consistent.

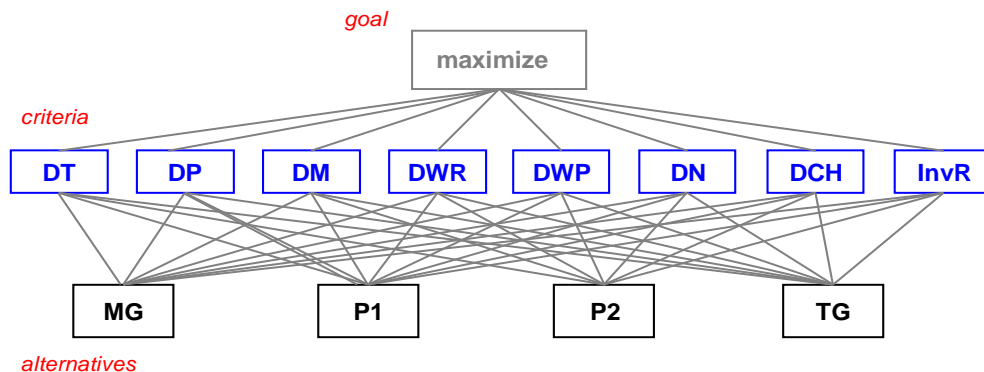
There are several methods for calculating the eigenvector. Multiplying together the entries in each row of the matrix and then taking the  $n^{\text{th}}$  root of that product gives a very good approximation to the correct answer. The  $n^{\text{th}}$  roots are summed and that sum is used to normalize the eigenvector elements to add to 1.00. The results of MCDM analysis are given in the following Section.

## RESULTS AND DISCUSSION

### Site selection via combined MCDM

The combined MCDM approach was used for a detailed site selection, whereas Croatian strategic strengths are addressed. Weighting coefficients were estimated as normalized eigenvectors according to AHP. The goal was to maximize the distance between potential site and crucial areas and to minimize the route for transportation of waste from NEK (Fig. 3). Following the guidelines of national strategic documents [20,21] and taking into account important natural resources, eight criteria are implemented in this study (Fig. 3): distance from touristic areas (DT), distance from

metropolis (DM), distance from the nearest populated village (DP), distance from strategic groundwater reserves (DWR), distance from drinking water protected areas (DWP), distance from the nearest site/border of natural ecological network (DN), distance from significant cultural heritage (DCH) and inverse length of transportation route (InvR). Four alternatives for disposal site were evaluated. Aerial distances were calculated from the physical map of Croatia [36-41], while transportation route was obtained from Google.



**Figure 3.** Hierarchy for MCDM analysis  
**Slika 3.** Kriteriji višekriterijalne analize

According to the Croatian strategic frame for development from 2006 to 2013 [23] in a way to approaching EU standards, service sector (especially tourism) was recognized in terms of extensive growth. Furthermore, it is noted that Croatia is highly competitive in natural beauty, biodiversity, clean environment and consequently, tourism. In a way to adopt a concept of social cohesion, sports activities are interconnected with the Croatian strengths listed above. Apart from tourism, strategic directives evoke the social

responsibility, environmental protection, technological growth etc. The reduction of the overall appeal of tourist areas due to LILW repository was recognized as a great risk to Croatian economy.

Significance of each criterion was estimated with the relative grades from 1 to 7 according to the Saaty grades scale [34]. The highest importance is given to DT, DWP, DWR and DN while the lowest importance was put on InvR. The matrix for calculation of eigenvectors using AHP methodology is given in Table 2.

**Table 2.** Matrix for calculation of eigenvectors and consistency check (shaded cells represent the matrix A according to AHP)

**Tablica 2.** Matrica za izračun jediničnih vektora i provjeru konzistencije (zasjenjeni podaci predstavljaju matricu A prema AHP)

<i>criteria significance</i> <i>i</i> →	DT	DP	DM	DWR	DWP	DN	DCH	InvR	Eigenvector, $\omega = \frac{\sqrt{\prod_i \text{significance}_i}}{n}$	Normalized, $\omega_j = \omega / \sum \omega$	New vector, $\omega_n = \frac{\omega_j \text{significance}_j}{\sum_{i,j} \omega_j \text{significance}_i}$	$\lambda_{\max, i}$ ( $\omega_n / \omega_j$ )
<i>j</i> ↓	DT	1	3	5	1	1	5	7	2.1879	<b>0.2134</b>	1.7840	8.3592
DP	1/3	1	2	1/3	1/3	2	4	6	1.1718	<b>0.1143</b>	1.0095	8.8313
DM	1/5	1/2	1	1/5	1/5	1	1	4	0.5964	<b>0.0582</b>	0.5022	8.6333
DWR	1	3	5	1	1	1	5	7	2.1879	<b>0.2134</b>	1.7840	8.3592
DWP	1	3	5	1	1	1	5	6	2.1461	<b>0.2093</b>	1.7612	8.4130
DN	1	1/2	1	1	1	1	3	4	1.2510	<b>0.1220</b>	1.1042	9.0481
DCH	1/5	1/4	1	1/5	1/5	1/3	1	4	0.4767	<b>0.0465</b>	0.3923	8.4365
InvR	1/7	1/6	1/4	1/7	1/6	1/4	1/4	1	0.2336	<b>0.0228</b>	0.1944	8.5315

mean  $\lambda_{\max} = 8.5765 (>8)$

Results of consistency check →  
 (criteria defined in brackets)

CI = 0.0824

CR = 0.0584 (< 0.1)

This matrix involves human judgment; therefore, its consistency was checked. The CI was found to be 0.0824, while CR was 0.0584, proving the consistency of applied AHP approach. Finally, normalized eigenvector are used as weighting coefficients for the calculation of best alternative (Eq. (1)). The actual values of criteria DT, DP, DM, DWR, DWP, DN,

DCH and InvR are given in Table 3, along with the final scores for each proposed site. As it can be seen, the best alternative for permanent RW disposal is Trgovska gora, since this area is the most distant from tourist areas, groundwater reserves, drinking water protected areas and populated zones.

**Table 3.** Actual values of criteria (approximated aerial minimum distance in km) for different sites (alternatives) and MCDM result

**Tablica 3.** Stvarne vrijednosti kriterija (procijenjena minimalna zračna udaljenost u km) za različite lokacije (alternative) i rezultati MCDM-a

criterion ↓ site →	P1	P2	MG	TG	Results (normalized distance × $\omega_i$ )			
					P1	P2	MG	TG
DT	12	5	2	35	0.0732	0.0305	0.0122	0.2134
DP	7	4	4	5	0.1143	0.0653	0.0653	0.0816
DM	120	116	54	72	0.0582	0.0562	0.0262	0.0349
DWR	20	50	30	60	0.0711	0.1779	0.1067	0.2134
DWP	10	14	13	32	0.0654	0.0916	0.0850	0.2093
DN	5	5	1	13	0.0469	0.0469	0.0094	0.1220
DCH	20	40	4	40	0.0233	0.0465	0.0047	0.0465
InvR	1/256 <sup>§</sup>	1/199	1/134	1/163	0.0119	0.0153	0.0228	0.0187
results					<b>0.4643</b>	<b>0.5303</b>	<b>0.3323</b>	<b>0.9400</b> ( $A_{WSM}^*$ )

<sup>§</sup> real route thru existing highways and local roads

It needs to be pointed out that an east part of mountain Papuk is a special area: Geopark Papuk, a part of the European and Global UNESCO Geoparks Network [36]. Also, MG, P1 and P2 are near the public institution Lonjsko Polje Nature Park [42], which is one of the Croatian most notable touristic attractions. Nevertheless, Lonjsko polje is not the nearest tourist area to any site and was not considered during MCDM, but its proximity to MG, P1 and P2

additionally justifies the selection of TG as the most suitable location.

Areas with groundwater reserves are depicted in Fig. 4a. Due to the long-term plan for LILW repository, both existing water sources and groundwater reserves are included in MCDC. It needs to be emphasized that many protected areas in terms of drinking water sources are spread quite near MG, P1 and P2 [26] and TG is the only distant location.

## Expected environmental and social impact

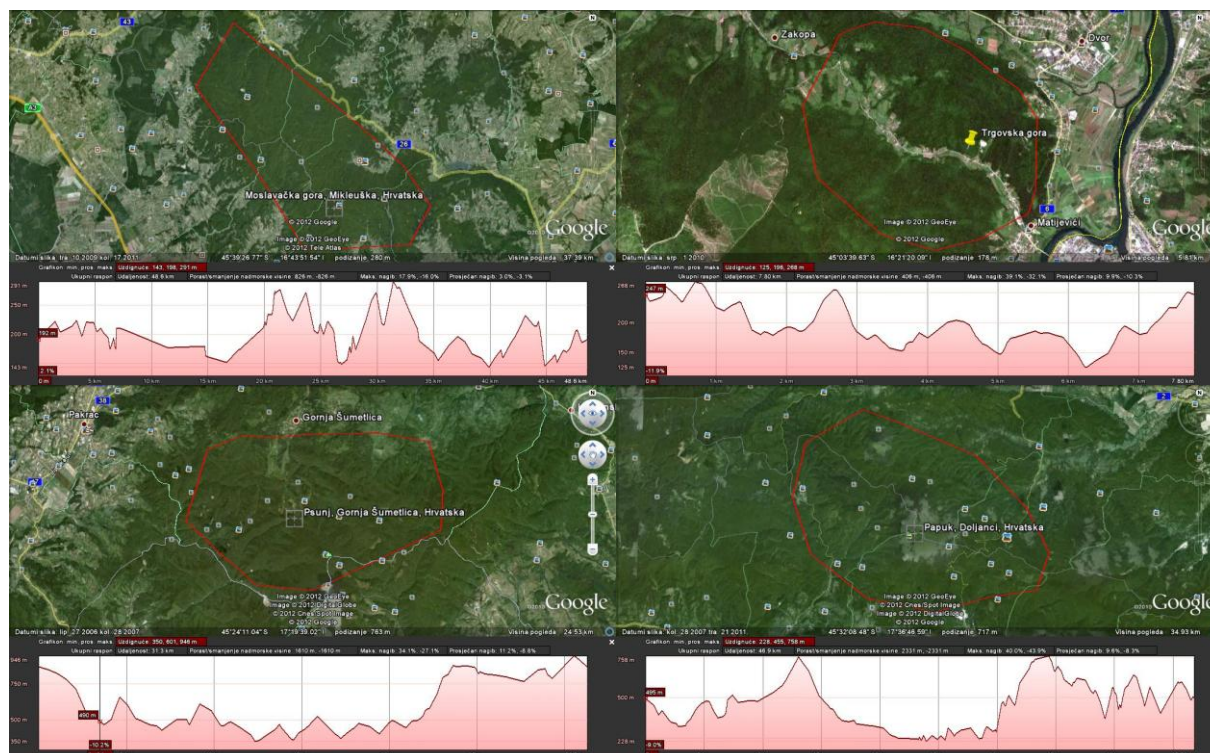
To evaluate the possible influence of LILW repository on each individual component of the environment, the intensity

and duration of the impact where estimated. Sum of all possible impacts is presented in Table 4.

**Table 4.** Sum of all expected impacts on the environment (white field – no impact; black field – significant negative impact; grey field - negative impact; light blue – positive impact; blue – significant positive impact)

**Tablica 4.** Sumarni prikaz svih očekivanih utjecaja na okoliš (bijela boja – nema utjecaja; crna boja – značajan negativan utjecaj; siva boja – negativan utjecaj; svijetlo plava boja – pozitivan utjecaj; plava boja – značajan pozitivan utjecaj)

Impacts	Preparation works (excavations)	Working period (disposal)	After recovery (closure)
<b><i>People, current structures and property</i></b>			
Population changes			
Landscape changes			
Noise			
Local roads and transportation			
Archeology and heritage			
<b><i>Flora, fauna, woods, geology</i></b>			
Flora			
Fauna			
Forrest			
Geomorphology and geological characteristics			
<b><i>Land and its use</i></b>			
Erosion			
Soil contamination			
Agriculture			
Ability for use in other purposes			
<b><i>Water</i></b>			
Drainage			
Emission in groundwater			
<b><i>Air</i></b>			
Dust emission			
Gas emission			
<b><i>Other effects</i></b>			
Energy supplies			



**Figure 4.** (a) Strategic groundwater reserves (red, green and blue areas) according to Croatian water management strategy (Biondić, 2009); (b) Wind rose in the vicinity of the proposed location (Trgovska Gora); courtesy of Meteorological and Hydrological service, Croatia, 2012; (c) Relief-dissection of four alternative locations (MG, TG, P1 and P2); courtesy of Google GeoEye

**Slika 4.** (a) Strategija zaliha podzemne vode (crvena, zelena i plava boja) prema Strategiji upravljanja vodama u Republici Hrvatskoj (Biondić, 2009); (b) Ruža vjetrova na području predložene lokacije (Trgovska Gora); prema podacima Državnog hidrometeorološkog zavoda, Hrvatska, 2012; (c) Reljefni presjek četiriju alternativnih lokacija (MG, TG, P1 i P2); preuzeto s Google-a i GeoEye-a

The impact on climate and air quality is estimated as minor. During the preparation of the project and construction of the repository, there are the presence of smoke, air pollution, airborne particles and dust. Construction machinery with fossil fuel engines pollutes the atmosphere with exhaust gases. There are also vehicles for the transport of excess excavation and transportation of construction materials. In very dry weather, there may be pollution associated with dust carried by the wind. All these phenomena are only temporary and occur in a stage of development, so there is

no additional long-term harm to the environment. During the operational phase, the air is polluted only with exhaust gases during transportation of waste from NEK to the landfill and in the case of accidents. With the closure of the repository, there is air pollution, dust, smoke and particulate matter in the process of burying the silo due to the operation of construction machinery. To prevent further pollution, it is very important to be acquainted with basic meteorological indicators: temperature, downfalls, humidity and winds; all of them by their direction, intensity and frequency. By the Koppen



classification, Sisačko – moslavačka county is in climate zone C: temperate/mesothermal climates with warm summer. Average temperatures are between -2 and 0 °C in January and between 18 and 22 °C in July. Average annual temperatures for the period from 1982. – 2011. are given in Table 5 [43]. The area of the county has many areas of different amount of downfalls per year, therefore in the district of Dvor area there is

1000 – 1500 mm of downfall per year, evenly distributed through the year with maximums in the spring and autumn. Snow maintains on the soil most often up to 40 days per year. Average yearly relative humidity is 76.5% which varies from medium to very high through the year. Minimum is in the winter months while maximum is in the summer months. The meteorological data is given in Table 5.

**Table 5.** Meteorological data summary for TG (according to Sisak station measurements; Meteorological and Hydrological Service, 2012.)

**Tablica 5.** Zbirni prikaz meteoroloških podataka za TG (prema podacima mjerne stanice u Sisku i podacima Državnog hidrometeorološkog zavoda, 2012.)

Decade	Yearly averages		Averaged year values		
	Temperatures (°C)	Relative humidity (%)	Amount of downfall (mm)	Number of days with snow cover $\geq$ 1cm	Sunny days
1982-1991	11.39 $\pm$ 1.45	-	863.95	-	-
1992-2001	11.60 $\pm$ 1.51	-	933.02	-	-
2002-2011	11.64 $\pm$ 0.98	78 $\pm$ 6	924.62	9-56	48 $\pm$ 17
30-year average	11.525	80*	907.197 (max 1284.3 mm in 2010)	37*	45*

\* it is an approximation; some data are missing due to certain circumstances

Number of days with strong wind in a year is 9.9 with 1.1 day of strong storm wind. By the data from national Meteorological and Hydrological Service [43], average yearly distribution of wind direction is as follows: from NE (15.4%), N (13.0%), W (11.7%), SE (11.6%), SW (11.3%), E (9.5%), NW (9.4%), S (4.5%) (See Fig. 4b). While, during approximately 13.6% of the year there is no wind. The given wind distribution favors the selection of the certain site. Mostly, the wind directions are evenly distributed towards less inhabited area of Croatia.

The main negative impacts on soil are therefore related to the period of construction of the planned landfill, when

there will be a permanent and temporary conversion of soil. Permanent land use changes, and loss of soil functions, refer to the limited space where the repository will be constructed. The proper site organization is essential for the construction phase, prescribed measures and standards have to be obeyed, and the control of responsible authorities is necessary because it significantly reduces the chance of harmful effects. Non-compliance with the rules and procedures when handling fuel, lubricants, paints, solvents and other chemicals used in the process of construction is harmful because they can get into the ground. Related minor accidents should be avoided. The stability of the silo insulation after

backfilling has to be checked to prevent soil contamination. Furthermore, Trgovska gora is horst-type mountain; a forest area with severe limitations for agriculture, i.e. Class 4 according to the agricultural land classification of soil [44]. Generally, area of Sisačko – moslavačka county is mostly consisted of Holocene and Neogene deposits. Those are areas of sediment deposits that originated in younger geological period. However, the hill area (Zrinska gora, Petrova gora and Trgovska gora) is of more complex geological structure. Old magma rocks from Paleozoic covered with sediments from Mesozoic and quaternary are dominant at those areas. Owing to the numerous ridges, Trgovska gora is morphologically dynamic area with relatively high vertical dissection and slope (Table 1., Fig. 4c), thus appropriate for underground LILW repository. Several studies confirmed the use of this area for a special purpose landfill [45, 46].

All waterways in the studied area belong to the watershed of river Sava. Based on the National plan for water protection, Una river belongs in international waters and a part of Una is in karst region. A special precaution need to be taken, and a project boundary should not exceed borders of stable area of Una aquifer. Non-compliance with the rules and procedures when handling fuel, lubricants, paints, solvents and other chemicals used in the process of building, can lead to the infiltration in the soil, and thus indirectly to groundwater. Improper handling of hazardous waste can also pollute groundwater. Inadequate sewage disposal and fresh water from the site can also threaten groundwater, but also the health of employees. Given that the chosen location does not have significant amounts of groundwater, with proper organization and control it is estimated that the impact on the water during construction will be very low. The area has an abundance of streams that belong to the basin of the river Una, and

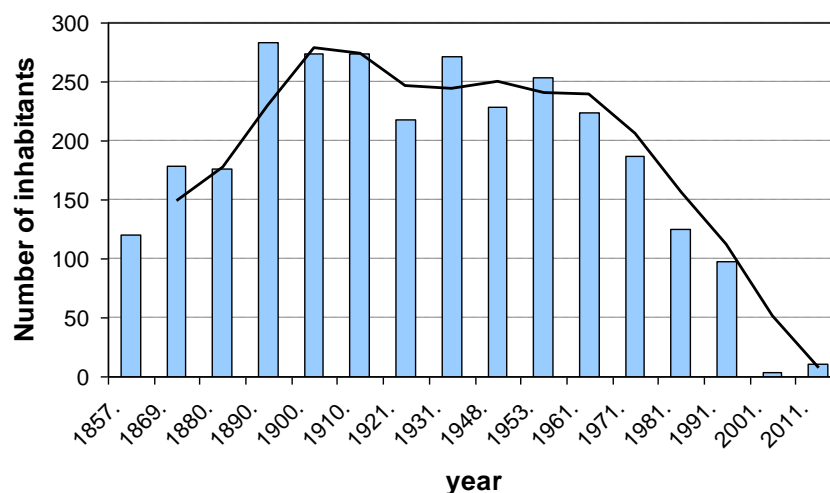
during construction, due to blur, temporary and short-term negative impact on the quality of surface waters is possible. In the case of accidental contamination during transport, surface water and groundwater can be polluted with radioactive waste. This is the one of the major hazards of the project and it must be evaded, primarily by employing the highly qualified, competent and responsible individuals and contractors. After closure, temporary collector tank must be emptied so its content would not migrate into the groundwater.

Impact on flora is evaluated as negative; the meadows, pastures and a small part of the forest will suffer. Very small and fragmented land under forest vegetation near the impact area will not be affected by building this facility. During the construction, impact on fauna will respond to changes in habitat or loss of the habitat due to the formation of the working zone. In addition, removal of vegetation, digging and generally increased movement of heavy machinery in the habitat will certainly lead to direct harm to a number of animals. This is especially true of poorly motile animals and those that live in the soil, but also the birds that nest in the trees scheduled for cutting. Some animals will escape. Nevertheless, as this is a relatively short period of time animals can adapt quickly. In addition, works outside the reproductive period of the animals, and taking into account the presence of the nest, these negative impacts can be reduced to acceptable levels. During operation, radiation levels must be monitored according to the basic safety standards [1].

During the construction works, usual construction machinery will be applied, with typically average level of noise up to 80 dB. Increased noise levels at the location have only a temporary character and a short-term impact. During operation, trucks generate a significant noise only during transport, and there is no noise impact after closure.

In the County, an uneven population density is expressed, which manifests itself in the dense populated urban areas of the County (Sisak, Petrinja, Kutina, Novska) and some deserted villages (rural areas of Banovina and Posavina). Out of 4 people who live in the village of Majdan, the age structure of the population indicates the dominance of the population older than 60

years old (3 people). No inhabitant was younger than 30 years, and one inhabitant is of the age between 30 and 60 years [47]. The village population is aging which marks the decline of the younger population and the increasing proportion of older people in the total population. Particular emphasis is migration, depicted in Fig. 5.



**Figure 5.** Population data and trend for the village nearest to site TG (Majdan, approx. 5 km)

**Slika 5.** Podaci o broju stanovnika i trend za naselja u blizini lokacije TG (Majdan, približno 5 km)

The disposal site is located in an uninhabited area, and given the distance from the village Majdan will have a negligible impact on the surrounding population. Due to increased frequency of transport of materials and techniques, the location of the construction may change the traffic conditions, it will require special attention, and control of traffic, with a benefit of sparsely populated areas. During the operational phase the most important is the health impact of stored waste on the health of workers. The adequate system of monitoring is very important. With the termination of activities, monitoring of radiation levels in the area over the next 100 years must be provided. A minimum of one

Geiger counter in the silos and two Geiger counters outside: one in the complex area and one at the edge of the site area must be installed. The system must be designed so that in case of exceeding limits of permitted radiation alarm immediately alerts all employees and relevant government agencies (e.g. *State Office for Radiological and Nuclear Safety*) which further alerts the authorities. A system of monitoring radiation levels near the border with Bosnia-Herzegovina, in agreement with their respective ministry should be established.

Disposal is anticipated within 20 years after which the silos are permanently buried up and radiation levels in the area are monitored over the next 100 years.

Appropriate warning signs must be put up in the area so the local population and visitors are aware of the risk that this area represents. A compliance with those requirements will result in minimization of potential negative influences on human health and environment in general.

Nevertheless, regardless to the results of technical reports and expert opinion [13],

## CONCLUSION

Living in 21<sup>st</sup> century and being part of a technological society, means we must confront consequences responsibly. People in Croatia utilize the power produced in NEK, thus the waste is our responsibility. Additionally, large quantities of wastewater are generated in households on daily basis, leading to the enormous quantities of sewage sludge at the endpoint of WWTPs. On our way to sustainable development, society must confront emerging environmental issues and accept the solutions provided by experts in the corresponding areas.

It was shown that there is an adequate location (Trgovska gora) and applicable technical solution (underground silos, 90 m in depth) for storage of LILW in Croatia. As analyzed by EIA elements, the solution includes an efficient environmental

even bringing the idea of Trgovska gora as possible location for constructing of radioactive waste disposal has raised strong refuse and objection in the local community which was expressed by non-governmental environmental association of citizens KAOS from Hrvatska Kostajnica through different activities in the last decade [48].

protection. A simultaneous preservation of Croatian strategic focal points (tourism and groundwater reserves) was taken into account by applying the MCDC.

Moreover, since radioactive waste landfill presents an important element in environmental protection it is considered as "controversial object" in public. In most cases public will do anything to stop construction of radioactive waste repositories in its neighborhood according to "not in my backyard" approach. Such behavior of public is a result of the lack of information and doubts in truth of given explanations. However, environmental protection has to be a joint concern of all the stakeholders, not just "chosen" individuals or groups, so the public has to be involved in the EIA process from the beginning as well.

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