Application of Multicriteria Analysis in the Selection of the LNG Terminal Location

Primjena višekriterijske analize u odabiru čokacije LNG terminala

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Abstract

Positioning of large energy facilities is, as a rule, accompanied by a strong rejection of local and regional communities, without which it is not possible to determine the location and construction conditions for the facility in spatial plans. However, a synergy of three components may enable a successful project realization. Firstly, the application of verified and objective scientific methods for the selection of the most appropriate LNG terminal location. Secondly, the consideration of the best world practices in project documentation preparation for such terminal construction. And lastly, the continuous involvement of the local community into the entire process. The paper presents an approach aimed at solving the problem of choice by applying the methodology of choosing the "best compromise location" based on system characteristics, available data, set criteria, and limitations. The key "dimension" of such a problem is "space", i.e. the spatial aspects of location selection. The paper provides an overview of the activities, procedures, and methods used to define the optimal location of the receiving LNG terminal in the Republic of Croatia as part of the analysis and research carried out by EKONERG and in the function of creating the Spatial Plan of Primorje-Gorski Kotar County. Accordingly, the main objective of this paper was to highlight the specifics of LNG terminal site selection as well as the possibility of objectively defining the optimal location using the multi-criteria decision-making method that simultaneously takes into account all influential factors and criteria in defining it. The paper uses the methodology of multi-attribute decision process and multicriteria analysis of the selection of the optimal location of the LNG terminal on the territory of Primorje-Gorski Kotar County. It systematically and scientifically analyses, consistently formulates, and proposes elimination and comparative criteria necessary to determine the optimal location of the LNG terminal for the purpose of drafting regional level spatial planning documents. The presented methodology was carried out using the process of multicriteria ranking of variants. The method of weighted sum values was used. Weighting factors are determined partly in an exact way (where possible) and partly based on the application of Delphi group decision-making methods. The methodology was tested on a concrete example of variant analysis for the location of LNG terminals in the Republic of Croatia. By implementing the presented methodology, the location of the northern part of the island of Krk was determined as optimal for the location of the LNG terminal. The aforementioned was implemented in the Spatial Plan of Primorje-Gorski Kotar County, and the first phase of the receiving LNG terminal was built and put into full operation.

KEY WORDS

liquefied natural gas terminal (LNG terminal)
spatial planning
multicriteria analysis
Delphi method
the Primorje-Gorski Kotar County
Croatia

Sažetak

Pozicioniranje velikih energetskih objekata u pravilu je popraćeno snažnim otporom lokalne i regionalne zajednice, bez kojih nije moguće prostornim planovima odrediti lokaciju i uvjete izgradnje objekta. No, sinergija triju sastavnica može omogućiti uspješnu realizaciju projekta. Prije svega, primjena provjerenih i objektivnih znanstvenih metoda za odabir najprikladnije lokacije LNG terminala. Drugo, uvažavanje najbolje svjetske prakse u izradi projektne dokumentacije za izgradnju takvog terminala. I na kraju, kontinuirano uključivanje lokalne zajednice u cijeli proces. U radu se prikazuje pristup usmjeren na rješavanje problema izbora primjenom metodologije izbora „najbolje kompromisne lokacije" na temelju karakteristika

KLJUČNE RIJEČI

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sustava, dostupnih podataka, postavljenih kriterija i ograničenja. Ključna je „dimenzija“ takvog problema „prostor“, odnosno prostorni aspekt odabira lokacije. Rad daje pregled aktivnosti, postupaka i metoda definiranja optimalne lokacije prihvatnog LNG terminala u Republici Hrvatskoj u sklopu analiza i istraživanja koje provodi EKONERG, a u funkciji izrade Prostornog plana Primorsko-goranske županije. Sukladno s time, glavni cilj ovog rada bio je istaknuti specifičnosti odabira lokacije LNG terminala, kao i mogućnost objektivnog definiranja optimalne lokacije višekriterijskim načinom odlučivanja koji istovremeno uzima u obzir sve relevantne čimbenike i kriterije. Koristi se metoda višeatributnog odlučivanja i višekriterijske analize odabira optimalne lokacije LNG terminala na području Primorsko-goranske županije. Sustavno i znanstveno analiziraju se, dosljedno formuliraju i predlažu eliminacijski i usporedni kriteriji potrebni za određivanje optimalne lokacije LNG terminala za potrebe izrade prostorno-planskih dokumenata na regionalnoj razini. Prikazana metodologija provedena je postupkom višekriterijskog rangiranja varijanti. Koristi se metoda ponderiranih zbrojnih vrijednosti. Težinski faktori određuju se dijelom na egzaktan način (gdje je to moguće), a dijelom na temelju primjene Delphi grupnih metoda odlučivanja. Metoda se testira na konkretnom primjeru analize varijanti lokacije LNG terminala u Republici Hrvatskoj. Primjenom predstavljene metodologije, sjeverni dio otoka Krka određen je kao optimalna lokacija za smještaj LNG terminala. To je implementirano u Prostorni plan Primorsko-goranske županije te je izgrađena i puštena u puni pogon prva faza prihvatnog LNG terminala.

1. INTRODUCTION / *Uvod*

European states' dependence on Russian oil and gas and the uncertainty about meeting energy needs are more than pronounced today. In order to diversify natural gas supply routes, the EU encourages the construction of liquefied natural gas receiving terminals [1,2].

The construction of LNG terminals is a significant economic activity. It activates spatial and economic potentials in compliance with the requirements of the purpose of the premises, environmental and securities guidelines as well as the availability of infrastructure and other elements necessary for the functioning of the terminal without significantly negatively influencing the people and the environment.

The fact is that investments in transport infrastructure are very complex due to the influence of many parameters and the changing environment in which projects are realized. To date, no unambiguous acts have been adopted to determine the conditions for the selection of optimal locations of LNG terminals, neither in Croatia nor in EU countries. Since no unequivocal legal acts officially define the conditions for selecting the optimal locations for LNG terminals, in practice it is possible to use part of the criteria used for selecting the location of large capital infrastructure such as thermal power plants or nuclear power plants. [4]. Locating the LNG terminals as well as the topic of optimization of routes for the service of LNG terminals are of particular importance. One of those methods is multicriteria analysis [5-9].

As these are facilities that can have a significant impact on people and the environment, it is particularly important to establish the optimal location of the terminal, which will ensure maximum economic benefit with minimal negative impact.

The paper presents an approach aimed at solving the problem of choice by applying the methodology of choosing the "best compromise location" based on system characteristics, available data, set criteria, and limitations. The key "dimension" of such a problem is "space", i.e. the spatial aspects of location selection. Since this is a highly sensitive social topic, when choosing the most appropriate terminal location, one must be impartial, treating the entire space equally and in detail. All evaluating participants must be engaged in the same way, experiencing the limitations and benefits of the space in question, i.e. its positive and negative features, focusing most intently on the features associated with the elimination criteria. [3]

The paper uses the methodology of multi-attribute decision process and multicriteria analysis of the selection of the optimal location for the LNG terminal on the territory of the Primorje-Gorski Kotar County in the Republic of Croatia. The analysis [4] served for drafting the Spatial Plan of the Primorje-Gorski Kotar County, which defines the location and basic conditions for the accommodation of LNG terminal.

In the subject analysis of the optimal LNG terminal location selection made for the needs of the Primorje-Gorski Kotar County Spatial Plan, the selection of the terminal location is based on a complete analysis of the problem and with the inclusion of a wide range of stakeholders of all interest groups, with the aim of harmonizing the economic, social and environmental interests that strive to meet long-term goals and needs of the covered settlements, regions, and the country. It sought to balance the obvious contradictions between the economic, social, and environmental interests that arise to meet the long-term objectives and needs of the settlements, the region, and even the state covered. The final decision on where and under what conditions the LNG terminal can be located is the result of a complete analysis and assessment that examined each eligible location in a particular area [10].

To explore the complete space of Primorje-Gorski Kotar County and to determine the optimal locations for the accommodation of LNG terminals, comparative analysis and evaluation of potential locations were carried out through which the basic criteria for the placement of LNG terminals were determined. In this particular case, the selection of criteria and the evaluation of weighting factors for each of the criteria and related subcriteria were carried out by the Delphi method of group decision-making [4,10].

One of the most important criteria for choosing the location of LNG terminals is the maritime conditions of accepting large LNG ships. Another important criterion is the possibility of connecting LNG terminals to the main pipeline network. Other than the aforementioned criteria, there are a whole range of spatial, environmental and other criteria for the construction of LNG terminals, dictated by the technical, environmental and economic logic of the project, which need to be fulfilled if the project is to be realized [2,11-15]. It is clear that at the site selection stage it is necessary to collect field data in order for the evaluation to be carried out. It is then necessary to combine collected data with available topographic, geological, meteorological, maritime, and other substrates and fold them with thematic maps of environmental protection and space purposes. These are followed by an evaluation of the mentioned data and thematic maps according to the defined criteria. [16].

After determining variants of possible locations of LNG terminals, in accordance with the methodology of the multi-criterial ranking of variants procedure, the parameters of certain criteria within the thematic groups of evaluation criteria were established. In accordance with defined criteria and corresponding weighting coefficients, a multicriteria analysis of the evaluation of variants is carried out which with its methodology guarantees functionality, reliability and objectivity in determining the location of the LNG terminal. The analysis carried out proves the reliability and functionality of the offered methodology.

2. THE SPECIFICITIES OF THE SELECTION PROCEDURE FOR THE LNG TERMINAL LOCATION IN THE REPUBLIC OF CROATIA / *Specifičnosti postupka odabira lokacije LNG terminala u Republici Hrvatskoj*

First step in the realization of the LNG receiving terminal is its planning in the spatial planning documents based on which further procedures necessary for obtaining the acts for construction are carried out. Spatial planning documents are the basis for the reflection of spatial development. The carriers of development of the spatial planning documents are, in addition to the state, the units of regional and local self-government, and are adopted by representative bodies of citizens (the Parliament of the Republic of Croatia, the county assembly or the city/municipal councils) depending on the level of the spatial planning document. This is why not only experts participate in the selection of the most favorable - optimal variants/solutions in spatial planning, but very often also politicians (without specialized expertise) as well as the public (through mandatory procedures for conducting public consultations and public discussions in the process of adopting spatial planning documents) play a crucial role. Here the multicriteria analysis proves to be the most objective tool for choosing the most favourable terminal location and its presentation [17], which is why precisely this method was chosen for the selection of the receiving LNG terminal location in the Republic of Croatia.

The stages of selecting the optimal location of the LNG receiving terminal are [18]:

1. determine the specificities of the facility/plant (spatial and technological) for which the analysis is carried out;
2. preliminary definition of the analyzed area (wider choice);
3. define elimination and comparative criteria;
4. visiting locations, collecting field data and available professional and scientific literature for evaluation purposes, redefining a wider selection of locations;
5. applying elimination criteria and defining a shortlist of locations;
6. collection of relevant data for shortlisted locations;
7. a detailed description of the locations of the shortlist and evaluation according to defined comparative criteria;
8. ranking of locations and selection of the optimal location of the LNG terminal.

Thematic groups of criteria and subcriteria were defined to set the model of evaluation and selection of the optimal location for the LNG receiving terminal and their evaluation was carried out [4]. Nonetheless, the determination of the eliminating and comparative criteria posed a particularly significant challenge. After having conducted a systematic analysis, which also involved a wide range of stakeholders, a total of nine elimination and 13 comparative criteria were determined. Carrying out a multi-criteria analysis of the selection of the optimal location based on the specified criteria in the specific example proved to be appropriate.

The LNG receiving terminal covers only part of the "LNG chain" of liquefied natural gas transport, and consists of a receiving terminal and a main pipeline for gas transport to interested gas customers [16,19,20].

In order to successfully look into the spatial needs but also to evaluate the possible effects of LNG terminals in the first step of the evaluation process, it is necessary to know its basic technical and technological elements and characteristics. Thus, before the process of valuing the premises for the accommodation of the LNG receiving terminal, it is necessary to determine the scope or dimensions of the receiving LNG terminal in the maximum (final) dimensions. This is followed by a projection of spatial needs and opportunities to accommodate the LNG terminal. In the present case, the LNG terminal is seen as a synergy between the land and sea parts of the terminal:

- Land facilities:
  - three reservoirs with a single capacity of 195,000 m^3 of LNG, a tank diameter of 88 m and a height of 53 m;
  - groups of major technology facilities;
  - groups of auxiliary facilities.
- Maritime facility:
  - a single mooring for the reception of a ship with a length of 300 m, a width of 60 m and a height of 25 m, with a draught requiring a sea depth of at least 15.50 m.

The construction of LNG terminals in the Republic of Croatia is planned in phases up to a maximum capacity of 15 billion m^3/year. Natural gas would be brought with LNG ships with capacity of 75,000 to 265,000 m^3. Four unloading arms with a designed flow rate of 16,000 m^3/h would be used for the transshipment of LNG ships. Unloading the total amount of LNG from tanks with a volume of 130,000 m^3 would take a total of about 12 to 13 hours. Depending on the countries from which LNG is supplied in the first phase, 120 to 180 ships per year were expected to dock. Looking at the total capacity of the terminal, it was assessed that for its realization it is necessary to provide about 35 - 50 ha of land with the appropriately protected dock for ships.

In the early 1990s, at the level of geostrategic decision-making, the area of the northern Adriatic, as the area most deeply embedded in the European mainland, was recognized as a potentially optimal area for the accommodation of the reception terminal in the Republic of Croatia. Given the geostrategic position, most of Central and Southeastern Europe can easily be supplied with natural gas from this area.

On the basis of the general requirements that must be met by the location of the LNG terminal, two potential wider macro-locations were singled out and analyzed: the area of the port of Koper (in the Republic of Slovenia) and the area of the port of Rijeka (in the Republic of Croatia). A comparative analysis of the maritime indicators of the mentioned macro-locations resulted in the conclusion that the port of Rijeka (Kvarner Bay) is a better choice for the location of the LNG terminal. The results of the analysis of comparative maritime indicators were key when choosing a broader macro-location. Furthermore, given the tourist orientation of the Republic of Croatia, from the national level it has been confirmed that the analysis of the locations for the accommodation of LNG terminals should be carried out exclusively within the premises where there are already significant industrial and energy facilities. Following the above, it was concluded at the national level that it is justified to analyze the northern part of the Croatian coast, i.e. the wider area of the Kvarner Bay in the Primorje-Gorski Kotar County, and that other areas of the Croatian coast should not be included in the analysis.

In the next phase, the determination of macro-locations within the Kvarner Bay (the bay where the port of Rijeka is located with its five basins) was carried out. The main criterion for determining macro-locations within the Kvarner Bay was to direct them to spaces that have already been used or are intended in the spatial planning documents to accommodate industrial or port zones or zones of similar purpose. In doing so, the aim was to avoid areas that are in extreme conflict with the planned facility (settlements, tourism, protected areas of natural and cultural heritage, etc.). In this way, four larger potential areas (macro-locations) were selected for more detailed processing [21].

Within the macro-locations determined in the previous step, the existing use and the planned purpose of the premises are analyzed in more detail. A preliminary analysis of the maritime preconditions for the reception of LNG ships and the possibility of connecting a potential LNG terminal to the main gas network was also carried out. Table 1 shows pre-elimination criteria based on which the pre-elimination procedure of individual locations was carried out.

Table 1 Pre-elimination criteria

Tablica 1. Kriteriji za predeliminaciju

Criteria Identifier	Criteria
PE 1	Minimum sea depth 17 m
PE 2	Distance from the main gas pipeline up to 20 km

Source: Prepared by authors according to [22]

Two pre-elimination criteria that were taken into consideration are the sea depth of 17 meters and the distance from the main gas pipeline up to 20 kilometers.

On the basis of the pre-selection procedure carried out, taking into account the technical and technological as well as safety requirements of the object receiving LNG terminal, nine areas (micro-locations) were designated for further comparison. The listed macro- and micro-locations that meet the functional and technical conditions for docking LNG ships and gas evacuation and for which further evaluation is planned are shown in Table 2 and Figure 1.

Table 2 Macro and micro-locations for valuation

Tablica 2. Makro- i mikrolokacije za vrednovanje

Location Identifier	Macro-locations	Micro-locations
1a	Krk	DINA
1b		Blatna Bay
2	Bay of Bakar	Sršćica
3		Rijeka Thermal Power Station
4	Gulf of Raša	Podubac
5		Ubac
6		Sočaj
7	Gulf of Plomin	Plomin
8	Gulf of Raša	Zagrob Bay

Source: prepared by authors according to [4]

Krk Island, Bay of Bakar, Raša Bay, and Plominski Bay are potential micro-locations, within which nine micro-locations are defined, and which were evaluated using multi-criteria analysis.

Figure 1 List of potential locations for the accommodation of the LNG terminal

Slika 1. Popis potencijalnih lokacija za smještaj LNG terminala

Source: [4]

For the purposes of conducting a multi-criteria analysis, in the function of selecting the optimal location of the LNG terminal, it is necessary to define the following:

- elimination criteria that exclude the possibility of building an LNG terminal in certain locations and which therefore cannot represent a variant solution,
- comparative criteria used for the evaluation of acceptable solution variants.

Given that the quality of the selected criteria directly depends on the quality of the conducted procedure for the selection of the best variant and the correctness of the final decision, it is extremely important to determine the criteria and measures according to which the multicriteria analysis is carried out. The presentation of elimination and comparative (sub) criteria and the results of their evaluation are presented below.

2.1. Overview of elimination criteria / *Pregled eliminacijskih kriterija*

A significant step in the multicriteria analysis of the eligibility of LNG terminal locations concerns the definition of elimination criteria and the implementation of the procedure for excluding part of the ineligible areas from further evaluation. This refers to the exclusion of potential locations that are:

- Unsuitable for the construction of LNG terminals;
- Unavailable for the construction of LNG terminals;
- In apparent conflict with environmental requirements and
- Development which is extremely demanding from a technical and financial point of view.

An overview of the elimination criteria used is shown in the following Table 3.

Table 3 Elimination criteria
Tablica 3. Kriteriji eliminacije

Criteria Identifier	Criteria
E.1	Space for safe access and manoeuvre of the ship
E.2	Conflict with other existing and planned facilities in the area
E.3	Protected parts of the area
E.4	Dangerous geological fault
E.5	Available space to accommodate the terminal (>30 hectares)
E.6	Slope of the terrain greater than 32^0
E.7	Distance from ship to LNG terminal tank (maximum 2 km)
E.8	The average altitude of the site shall not exceed 60m above sea level
E.9	Distance form populated areas- up to 100 people up to a distance of 1 km

Source: Prepared by authors according to [22]

Below are individual justifications for the defined elimination criteria.

E.1. Space for safe access and maneuver of the ship

Areas that do not provide safe and reliable access to the ship are eliminated. The basic requirement is the possibility of accepting the largest LNG ships. Since the normal size of the ship's turnaround and docking area is two lengths of the ship, the location of the docking shall be in such a place as to provide an area of 700 meters of the sea surface, at least 17 meters deep, in all directions of the sea [4].

E.2. Conflicts with other existing and planned content in the area

According to this elimination criterion, the following are eliminated:

- special purpose areas (military facilities and plants);
- populated areas - existing and planned;
- areas of hospitality and tourism purposes, residential-tourism and sports-recreational purposes;
- manoeuvring zones of airports;
- area 200 meters from the motorway, state and county roads and railway lines;
- areas of protection zones of other industrial and commercial facilities.

E.3. Protected parts of the area

Locations in protected areas of the following categories are eliminated: strictly protected reserves, national parks, special reserves, nature monuments, significant landscapes, forest parks and monuments of park architecture of international and state importance.

E.4. Dangerous geological fault

Eliminated are also spaces in active geological fault zones where a shift (generated by an earthquake or as a result of continuous tectonic activity) can be expected, which may compromise the integrity of the terminal's essential objects. At the stage of application of the elimination criteria, it must be demonstrated that the fault is dangerous (capable fault) in order for the location to be eliminated (in the later stages it is the other way around).

E.5. Available space to accommodate the terminal

Areas that have a free land area of less than 30 ha are eliminated. The required area was assessed on the basis of the technical and technological as well as security requirements of the terminal.

E.6. Slope of the terrain greater than 32°

Areas, where the slope of the terrain is more than 32°, are also eliminated. Areas of steep terrain are unfavorable for the construction and use of the facility, taking into account the technical and technological as well as safety requirements of the facility.

E.7. Distance from ship to LNG tank

Areas where the distance from the ship to the LNG tank is more than 2 km are eliminated. The large length of the pipeline increases risk. Furthermore, the long pipeline increases the required gas pumping power, which can still function on existing vessels at a distance of up to a maximum of 2 km.

E.8. Average altitude of the location ≤ 60 m above sea level

Areas with an altitude above 60 m above sea level are eliminated. Although some terminal facilities can also be located in higher areas, the main structures and systems must be located lower. High sites significantly increase the price and adverse environmental impacts of terrain preparation, the sights of facilities as well as energy consumption for LNG transfer.

E.9. Distance from populated areas - up to 100 people up to a distance of 1 km

Existing and planned areas of settlements and tourist zones where more than 100 people permanently reside at a distance of 1 km from the potential location of the terminal on a year-round basis are eliminated. An area of 1 km is a zone in which one can expect the need to apply certain protection measures in case of an accident, including the so-called worst-case scenario.

Criteria E.1 to E.5 derive directly from technological requirements or from regulations. Other criteria (E.6 to E.9) are not conditional on technology or regulation, so they cannot be treated strictly on elimination. However, if they are not met, as a rule, there can be significant construction complications (E.7 and E.8), technological and security problems (E.6) or possible conflicts in relation to the public (E.9).

Considering the large number of vessels using the port of Rijeka and significant nautical traffic, the possibility of building a floating LNG terminal was initially ruled out.

2.2. Evaluation of locations based on the elimination criteria / *Ocjena lokacija na temelju eliminacijskih kriterija*

The result of this phase of multicriteria evaluation of the potential locations for LNG terminal based on elimination criteria was the rejection of the locations of identifiers 3 and 7. Both locations did not meet the E.5 Available area criterion.

Table 4 Evaluation of locations according to the elimination criteria
Tablica 4. Ocjena lokacija prema eliminacijskim kriterijima

Location Identifier	Micro-locations	Meets elimination criteria
1a	DINA	YES
1b	Blatna Bay	YES
2	Sršćica	YES
~~3~~	~~Rijeka Thermal Power Station~~	~~NO~~
4	Podubac	YES
5	Ubac	YES
6	Sočaj	YES
~~7~~	~~Plomin~~	~~NO~~
8	Zagrob Bay	YES

Source: Prepared by authors according to [4]

The remaining seven sites are essentially eligible for further analysis.

2.3. Overview of comparative criteria used / *Pregled korištenih usporednih kriterija*

The locations remaining after the application of the elimination criteria were evaluated, compared and ranked according to the location advantage of the LNG terminal accommodation, based on 13 comparison criteria determined by the expert's evaluation using the Delphi method [17; 19]. In doing so, the comparative criteria were divided into 5 groups of criteria, listed in Table 5, all with a purpose to ensure an objective evaluation.

By disassembling thematic groups of criteria into less complex components, a better approach to the process of multicriteria ranking of variants was provided, as well as the possibility of analyzing the results as well as drawing conclusions on the evaluation of individual alternatives.

Due to its importance in choosing the optimal location of the terminal, Comparative criteria U.1, U.2, U.3 and U.4, are divided into sub-criteria that are evaluated separately (Table 6).

The criteria values U.2, U.3 and U.4 are formed as the arithmetic mean of the sum of each of the sub-criteria according to (1).

$$U_{ij} = \frac{\sum_1^n U_{ij}}{n} \quad where\ i = (1-n) \tag{1}$$

where:

U_{ij} - assessed value of the location i by criteria j

n - number of sub-criteria within a specific comparative criterion

Only the value of the U.1 criterion is formed by assigning twice as much significance to sub-criteria U.1-2 and U.1-3 as to sub-criteria U.1-1 and U.1-4, using the formula (2):

$$U1 = \frac{(U_{1-1} + 2U_{1-2} + 2U_{1-3} + U_{1-4})}{6} \tag{2}$$

Other comparative criteria shall be formed in such a way that depending on the status of each location according to each of the criteria, the maximum amount of points 10 is reduced by the risk coefficients per each of the parameters (3).

$$U_{ij} = 10 - K_{ij} \tag{3}$$

where:

U_{ij} - assessed value of the location i by criteria j

K_{ij} - corrective factor on location i by criteria j

Table 5 Comparative evaluation criteria for the locations of the LNG receiving terminal

Tablica 5. Usporedni kriteriji ocjenjivanja lokacija prihvatnog LNG terminala

Criteria Identifier	Criteria Group	Criteria
U.1	Geological-seismological	Seismic and seismotectonic indicators
U.2		Seismic and seismotectonic indicators
U.3	Security	Conditions for docking and maneuvering the ship
U.4		Risk assessment in the area
U.5		Proximity and risk of impact of other industrial and risk facilities
U.6	Spatial Planning	The potential of conflicts in the area with other users of the area
U.7		The relationship of the location to the protected parts of the premises on or near the site
U.8	Ecological	Visual impact and impact on the landscape
U.9		Biological and ecological sensitivity of the location of the terminal and its immediate surroundings
U.10	Economic	Topographical conditions
U.11		Connection to the main gas network
U.12		Availability of infrastructure on site (road, building materials, water, electricity)
U.13		Possibility of building a gas burning power plant and other compatible facilities next to the location of the LNG terminal

Source: prepared by authors according to [4]

Table 6 Comparative criteria and sub-criteria for the evaluation of the locations of the LNG receiving terminal

Tablica 6. Usporedni kriteriji i podkriteriji za ocjenu lokacija prihvatnog LNG terminala

Criteria Identifier	Criteria	Sub-criteria Identifier	Sub-criteria
U.1	Seismic and seismotectonic indicators	U.1-1	Seismotectonic relationships in the wider area of the location
		U.1-2	Acceleration on the bedrock obtained by the probabilistic method
		U.1-3	Acceleration on the bedrock obtained by the deterministic method
		U.1-4	Influence of soil at the site on the amplification of earthquake-induced forces
U.2	Local geological conditions	U.2-1	Hydrogeological conditions at the site
		U.2-2	Engineering-geological (geotechnical) conditions at the site
U.3	Conditions for docking and maneuvering of ships	U.3-1	Maritime conditions (traffic of large, small and fishing boats as well as small craft and yachts)
		U.3-2	Traffic conditions (quantity of vessels and degree of traffic congestion on the waterway)
		U.3-3	Environmental conditions (wind, waves, tides, visibility, navigational barriers)
		U.3-4	Waterway conditions (limitation of visibility, size, type of bottom and seabed relief)
U.4	Risk assessment in the area	U.4-1	Number of people around the terminal
		U.4-2	Length of the LNG transfer pipeline

Source: Prepared by authors according to [4]

3. EVALUATION OF LOCATIONS AND RESULTS OF ANALYSIS / *Ocjena lokacija i rezultati analize*

Based on the established criteria for the evaluation of potential locations for the LNG terminal, an evaluation and comparison of all remaining locations was carried out. The evaluation results are presented in the following chapters.

3.1. Evaluation of locations based on comparative criteria / *Ocjena lokacija na temelju komparativnih kriterija*

Based on the assessment of the expert team and with the implementation of the Delphi method [10,17] aggregated results for the evaluation of potential locations on the basis of comparative criteria were obtained.

After the quantified results of the individual comparative criteria were obtained, the ranking of locations was carried out according to each of the criteria from best to worst by joining the location range from 1 to 7. Locations with the same score points were grouped in such a way that all the places they occupied were highlighted. For example, the comparative U.5 criterion has four locations with a total value of 10, while other locations have values of 4, 5 and 6. This means that the four locations with the highest value of the score ranked from fourth to seventh place (given that the other three are better ranked). In the final valuation stage, the average value of the site ranking is taken, in this particular case the average value would be 5.5.

$$U_{(4,5,6,8),U.5} = \frac{4+5+6+7}{4} = 5{,}5 \quad (4)$$

And in conclusion, the ranking of locations is summarized according to each of the comparative criteria and the final ranking of locations.

Then locations with the same absolute values are ranked in such a way as to assign them the average value of the levels they would occupy according to the algorithm below.

$$U_i(x_{ij}) = \frac{\sum NU_i(x_{ij})}{max\ x_{ij}} \quad for\ all\ U_{1-n}\ that\ have\ the\ same\ ranking(x_{ij}) \quad (5)$$

where:

U_i - parameter value function (features) x_i

x_{ij} - value of x_i at location j

N - number of locations with the same weighting factor values

max x_{ij} – maximum ranking of values of the same parameters

Table 7 Location value by comparative criteria
Tablica 7. Vrijednost lokacije prema usporednim kriterijima

Location	U.1	U.2	U.3	U.4	U.5	U.6	U.7	U.8	U.9	U.10	U.11	U.12	U.13	TOTAL
1a	3,9	3	8,6	5,9	4	6	6	9,5	9	8,5	1,2	8,6	4	78,2
1b	3,8	5,5	9,8	7,5	5	8	6	9,5	6	6,3	1,2	4,6	4	77,2
2	3,4	5	1,2	1	9	8	10	9	9	1	5	5	3	69,6
4	6,8	8	6,6	8	10	6	6	8	7	6,2	4,6	4,8	3	85
5	6,4	8	7	8,7	10	8	5	8,5	7	7	4	4,2	3	86,8
6	6,8	9	6,8	7,4	10	2	7	7,5	7	3,1	6,4	3,8	1	77,8
8	6,8	9	8,4	6,9	10	6	8	8	5	4,2	6,4	3,8	1	83,5

Source: Prepared by authors according to [4]

Table 8 Location ranking by comparative criteria
Tablica 8. Poredak lokacija prema usporednim kriterijima

Location	U.1	U.2	U.3	U.4	U.5	U.6	U.7	U.8	U.9	U.10	U.11	U.12	U.13	TOTAL (Σ min. values)	TOTAL (Σ max. values)
1a	3	1	6	2	1	2-4	2-4	6-7	6-7	7	1-2	7	6-7	50	58
1b	2	3	7	5	2	5-7	2-4	6-7	2	5	1-2	4	6-7	50	57
2	1	2	1	1	3	5-7	7	5	6-7	1	5	6	3-5	46	51
4	5-7	4-5	2	6	4-7	2-4	2-4	2-3	3-5	4	4	5	3-5	46	61
5	4	4-5	4	7	4-7	5-7	1	4	3-5	6	3	3	3-5	51	61
6	5-7	6-7	3	4	4-7	1	5	1	3-5	2	6-7	1-2	1-2	42	53
8	5-7	6-7	5	3	4-7	2-4	6	2-3	1	3	6-7	1-2	1-2	45	57

Source: Prepared by authors

Table 9 Comparative ranking of locations according to comparative criteria (with an average value of the same points)
Tablica 9. Usporedni poredak lokacija prema usporednim kriterijima (s prosječnom vrijednošću istih bodova)

Location	U.1	U.2	U.3	U.4	U.5	U.6	U.7	U.8	U.9	U.10	U.11	U.12	U.13	TOTAL
1a	3	1	6	2	1	3	3	6,5	6,5	7	1,5	7	6,5	54
1b	2	3	7	5	2	6	3	6,5	2	5	1,5	4	6,5	53,5
2	1	2	1	1	3	6	7	5	6,5	1	5	6	4	48,5
4	6	4,5	2	6	5,5	3	3	2,5	4	4	4	5	4	53,5
5	4	4,5	4	7	5,5	6	1	4	4	6	3	3	4	56
6	6	6,5	3	4	5,5	1	5	1	4	2	6,5	1,5	1,5	47,5
8	6	6,5	5	3	5,5	3	6	2,5	1	3	6,5	1,5	1,5	51

Source: Prepared by authors

3.2. Results of the analysis of the optimal location of the LNG terminal / *Rezultati analize optimalne lokacije LNG terminala*

The results of the analysis indicate that the locations on the northern part of the island of Krk (location 1a) and in the Bay of Raša (location 5) are of equal quality. The final verification concerned a comparative analysis of the ratings for the top two locations listed. It was found that location 1a is better by seven and location 5 by six criteria. As an advantage of the location in the Bay of Raša, good geological characteristics of the terrain and greater distance from the settlement were highlighted as an advantage. The main disadvantage are the less favourable maritime conditions compared to Krk.

The environmental protection criteria and spatial planning criteria have had better score/rang for location 1a. Finally, based on the multicriteria analysis carried out, location 1a DINA on the island of Krk was selected as the optimal location for planning and construction of the LNG receiving terminal.

Although the presented methodology of expert decision-making can also carry some subjectivity when selecting and evaluating criteria, it has been shown to be fully applicable for this level of decision-making. It has been proven that multicriteria decision-making can have a very wide application in the planning of the placement of infrastructure systems.

Restrictions on the conduct of a multicriteria analysis of location selection result primarily from the availability of data. Namely, the analysis itself at this stage does not include significant field research, but only field surveys. The entire evaluation is based on the available data from the research carried out and the results of the development documents of the spatial planning that processed the specified area (national, regional and local levels). In other words, the results of such an analysis are the selection of the optimal location for the implementation in the spatial planning documents.

It is important to stress out that before adopting regional spatial plans, it is mandatory to carry out an assessment of strategic environmental impacts (Strategic Environmental Assessment; SEA) assessing the likely significant environmental impacts that may result from the implementation of the planning document. [24]

Detailed elaboration of the accommodation of certain contents necessary for the operation of the entire LNG terminal is carried out in the design process.

Choosing a location for accommodation in spatial planning documents is only the first step to construction. Based on the planning conditions, more detailed design bases are prepared - conceptual solutions and an environmental impact study (the Environmental Impact Assessment; EIA). The EIA results in an assessment of the environmental impact of the planned operation, accepts or rejects certain interventions with regard to the estimated environmental impacts, i.e. prescribes measures to reduce the environmental impact of the intervention, which must be taken into account when preparing the conceptual project and issuing the location permit [25]. The location permit defines the conditions and phases of construction and conditions the elements that must be taken into account when drafting the main project as a basic act for obtaining a building permit. Obtaining a building permit, preparing the execution project documentation and bills of quantities create the final preconditions for making an investment decision on construction.

In future research, it would be important to elaborate in more detail all the elements of multicriteria decision-making and to define wider number of relevant criteria which are relevant for location of LNG terminal as well as determine which of the multicriteria decision-making methodologies is best used for each of the key stages of project implementation before and during the construction of infrastructure facilities and LNG terminals.

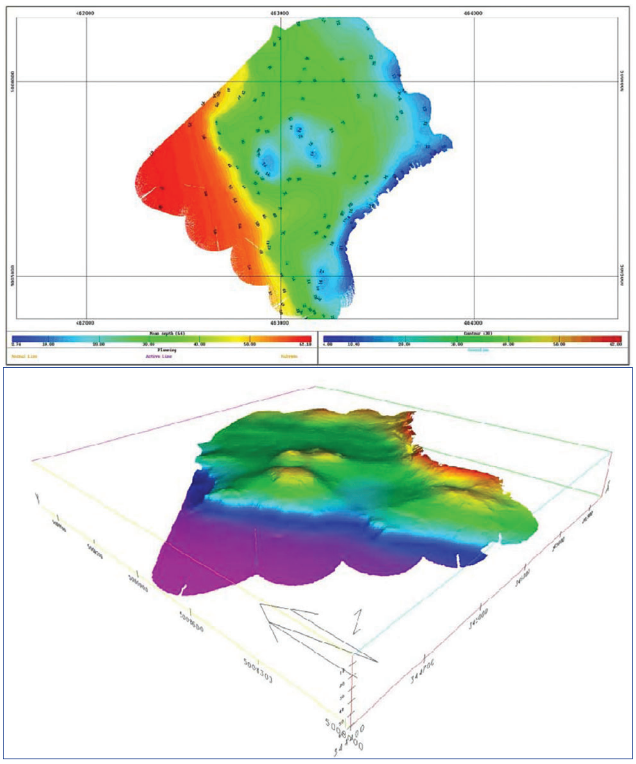

Figure 2 Sea depth and seabed relief within the best-rated LNG terminal location

Slika 2. Dubina mora i reljef morskog dna unutar najbolje ocijenjene lokacije LNG terminala

Source: [4]

Figure 3 Selected location to accommodate the LNG receiving terminal

Slika 3. Odabrana lokacija za smještaj prihvatnog LNG terminala

Source: [4]

4. CONCLUSION / *Zaključak*

In the paper, the multicriteria analysis for the selection of the location of the LNG terminal was carried out with four fundamental stages in the following order:

1. determination of possible locations of the LNG terminal;
2. evaluation of individual variants in accordance with the set criteria and sub-criteria;
3. comparing and ranking, i.e. evaluating individual variants;
4. decision on the optimal variant solution.

The definition of thematic groups of criteria and criteria for evaluation and selection was carried out on the basis of the consideration and evaluation of a number of experts. The practical application of the presented research proves the objectivity and comprehensiveness of the presented qualitative and quantitative criteria for determining the location of the receiving terminal for liquefied natural gas in regional spatial planning documents.

Based on the conducted research, it is concluded that without an adequate systematic approach in spatial planning through the conduct of quality preliminary research and the preparation of adequate professional bases in strategic spatial planning documents, it is not possible to unambiguously determine the optimal locations for infrastructure facilities.

With high-quality preliminary tests using complex multicriteria analysis, it is possible to determine the optimal location of the LNG terminal at the level of the regional level spatial planning document. In this way, it is possible to ensure the realization of the LNG terminal qualitatively and quantitatively in the function of satisfying economic, environmental, urban, energy, technical, technological, organizational, security and other aspects of development.

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