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GIS as a Support Tool for Sensitivity and Decision-Making Analysis for Transport Infrastructure Development

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Abstract: The sustainable implementation of highway projects requires a sensitivity analysis of the terrain and all of its components that have a direct influence on road design, construction and operation. The result of this inquiry involving GIS techniques and methods regarding environmental and economic factors helps in choosing the optimal road route, in order to meet the real-world connectivity requirements. The sensitivity analysis can be applied to road and rail infrastructure projects, aiming to develop a decision-making tool that can be employed by their potential beneficiaries, according to their purposes and interests. This paper aims to create an objective decision-making tool for transport infrastructure development in correlation with the current needs of society regarding the development of transport infrastructure in an economic sustainable manner with low environmental impact. Furthermore, the study tries to identify the best highway corridor in an area with environmental constraints (especially geomorphological), that is in balance with both environment and financial resources.

Keywords: GIS, transport infrastructure development, sensitivity analysis, decision-making analysis

1. Introduction

Sustainable transport has become an important goal in transportation planning and research in recent decades (Jacyna et al. 2018, Chamier-Gliszczynski & Bohdal 2016), especially with the development of Geographic Information System (GIS) techniques and methods (Rybarczyk & Wu 2010).

The sensitivity analysis is a mathematical method that examines the effect of changes in the values of input elements in the output values. In addition to the dependence between input / output data, the sensitivity analysis is a technique by which this dependence can be assessed and the importance of each input element in the generation of output data can be investigated. The sensitivity analysis is a key element in any decision-making analysis, especially in the field of transport (Ježek et al. 2018, Borgonovo 2017, Iooss & Saltelli 2015, Koltai & Terlaky 2000, Pandian & Kavitha 2012, Bonsall et al. 1977, Dodgson et al. 2009, Kabir et al. 2014, Saltelli et al. 2008).

The pioneers of these types of analyzes are Datzing (1950), who laid the foundations of the simplex algorithm for parametric programming, along with Orchard-Hays in 1952, Hoffman and Jacobs in 1952. Heller was the first author to mention the term sensitivity analysis in 1954. The sensitivity analysis as an essential part of the decision-making process was first highlighted by Samson (1988) and French (1986, 1989) (Gal 1997, Triantaphyllou 1997).

To date, the sensitivity analysis has become widely used within studies regarding the development of transport infrastructure, especially in alternative alignment studies as part of a multi-criteria analysis. As the weighting of the criteria is the least objective part of an analysis, mainly due to the fact that two individuals will not give the same weights due to individual assessments, the sensitivity analysis by developing different scenarios brings the results expected by the decision makers (Antov 2018). Taking all of this into consideration, we were not able to identify comprehensive studies regarding an integrated approach (from a strategic connectivity point of view), sustainable development of transport infrastructure by analyzing all the geographical environmental data and also alternative alignments objectively ranked to estimate as real as possible the environmental and cost impact for a future infrastructure project.

In order to develop a transport infrastructure unity across all member states of the European Union, as well as of the neighboring countries, the TEN-T Trans-European Transport Network was established, with two levels: TEN-T Core and TEN-T Comprehensive. The ultimate goal is to connect all regions of the European Union in a unitary, balanced, economically and environmentally sustainable manner.

In order to align to the European criteria, the Romanian Government has adopted the General Transport Master Plan of Romania, a strategic document which establishes and prioritizes transport infrastructure projects in Romania in the period from 2014 to 2030 and correlates them with the available funding sources (Bolos et al. 2016).

The adaptation of transport infrastructure to the needs and requirements of connectivity represents a priority at national, regional and European level and is based on several defining steps in regard to sustainable socio-economic development and environmental impact (Dobre & Păunescu 2020).

The process of identification, selection and implementation of infrastructure projects that are economically sustainable, with social benefit and in harmony with the environment prove to be defining stages and priority decision-making criteria (Dobre 2016).

This paper aims to create an objective decision-making tool based on scientific criteria utilizing GIS, in correlation with the current needs of society regarding the development of transport infrastructure in an economic sustainable manner with low environmental impact. Furthermore, the study tries to create a new methodology in objectively establishing and evaluating the analysis criteria, which would provide substantiated physical-geographical and socio-economic solutions. This can be applied to all geomorphotechnical assessments regarding transport infrastructure (road or rail) in order to refine the results by identifying optimal transport corridors in accordance with other environmental elements (Dobre et al. 2011, Păunescu et al. 2019, Schweikert et al. 2014, Jiang et al. 2015).

In order to highlight the usefulness and complexity of this scientific decision-making tool, it is necessary to apply the method in a heterogeneous area in terms of components and analyzed criteria, with geological and geomorphological variety, protected areas and high anthropic pressure (materialized by large built-up areas, either with logistical, agricultural or industrial areas or with new residential areas). In this context, the eastern metropolitan area of Brașov was chosen as a study area, an important pole of Romania's economic growth, located in the center of the country, at the intersection of several European and national transport corridors (Fig. 1).

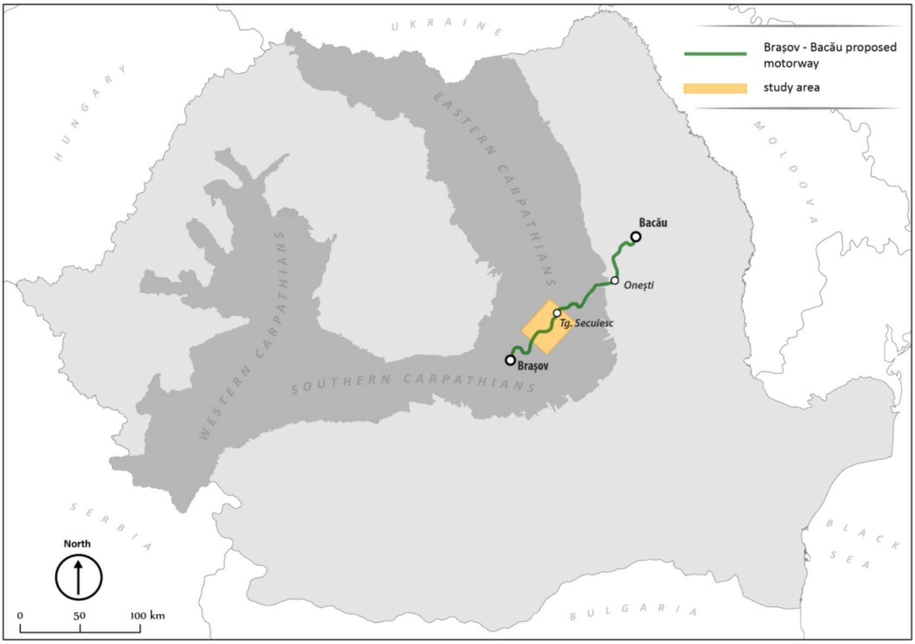

Fig. 1. Study area

2. Methodology

Scientific studies aimed at multi-criteria analyses are numerous and have emerged to solve the need for rationally and objectively choosing between the resulting solutions, in areas with obvious uncertainties. Despite the fact that the choice of criteria, attributes and their valorization were arguably difficult steps, multi-criteria analyses have proved their usefulness highlighting the obtained results level of performance and in general were a decisive indicator in making the most appropriate choice, depending on the interest of the beneficiary (Fig. 2).

The proposed methodology aims at an objective evaluation of the relevant environmental components (with emphasis on geological and geomorphological factors), in relation to the cost elements, which will ultimately lead to the identification of optimal decisions in relation to the needs of society regarding the implementation of a highway project.

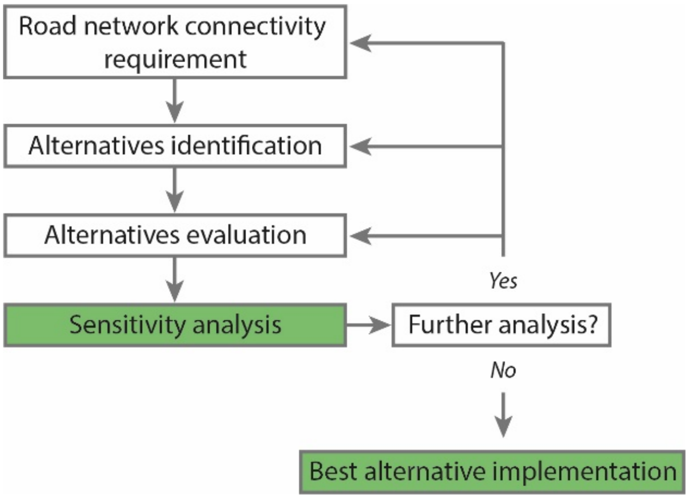

Fig. 2. Steps in decision-making process (modified after Borgonovo, 2017)

The present analysis consists of a geographical analysis performed with GIS modeling and a series of quantitative analyses, as part of an integrated study of applied geomorphology. The data sets used in this scientific approach are varied and have different scales and resolutions. For this reason, after data collection and introduction into the GIS environment, the first stage in this analysis consisted in standardizing and rescaling them, without losing the accuracy (Dobre 2016). The data sets relevant for the multi-criteria analysis are: map of protected areas, orthophotomosaic, topographic map, areas of geomorphological favorability, transport corridors, map of the hydrographic network and populated areas (Table 1).

In the proposed analysis, two criteria were taken into account:

a) environmental impact,

b) the influence of the geomorphological factor on a transport corridor.

Table 1. Digital data used

Data	Source	Topology	Characteristics (resolution, year etc.)
Natura 2000 protected areas	The Ministry of Environment	Vector	2015
Orthophotomosaic	The Ministry of National Defence (MaPN) and own data (UAV)	Raster	2017 (50 cm – MaPN, 10 cm – own data)
Topographic map of Romania (contour lines and elevation data), scale 1:25000	Military Topographic Directorate (DTM) and own data (RTK GPS)	Vector	1974 (DTM), 2020 (own data)
Areas of geomorphological favorability and restrictivity	Own data	Raster	2020 (5 m)
Transport corridors	General Transport Master Plan of Romania (GTMP) and own data	Vector	2016 (MPGT), 2020 (own data)
Hydrographic network	National Agency for Cadastre and Real Estate Advertising (ANCPI), own data	Vector	2012 (ANCPI), 2020 (own data)
Inhabited areas	Corine Land Cover 2018, own data	Vector	2018 (CLC), 2020 (own data)

Within the extended project, the research team is currently developing the integration of several factors in the sensitivity analysis (the relationship of the corridor with the anthropized areas, the pedological and geological factor, the hydrological factor, the impact on public utility networks, etc.)

Regarding environmental impact, the European Commission's Natura 2000 databases have been used. Natura 2000 is the cornerstone of nature conservation in the European Union. The environmental impact for each transport corridor was spatially calculated, depending on the percentage by which the corridor affects the crossed protected areas.

By crossing a transport corridor (a buffer zone at a distance of 70 m from the motorway alignment on each side) with a protected area, three components have been determined: the affected area (in hectares), the linear distance of the corridor within the protected area (in km) and the percentage of the affected area in relation to the total area of the protected area (in %). This enabled us to establish a hierarchical scale of transport corridors in terms of environmental impact in the final score (the relationship corridor/impact on protected areas was assessed in the range between 0 to 100, in progression from no impact to strong impact).

The protected areas in the analyzed area occupy approximately 14977 ha and they are classified into three categories: protected areas (NPA), sites of Community importance (SCI), special avifauna protection areas (SPA) (Table 2).

The influence of the geomorphological factor was determined following numerous field campaigns and by acquired geospatial data. The primary data source to represent the geomorphological factor is represented by the contour lines with equidistance of 5 m that were extracted from the Topographic Map of Romania (scale 1: 25.000, Military Topographic Directorate). These were used to create the digital elevation model (DEM), which was further enhanced by the addition of point field data (accuracy below 1 m) in the interpolation process, acquired with a RTK GPS device with ROMPOSS (**Rom**anian **Pos**itioning **S**ystem).

In the post-processing stage of the digital elevation model, the areas that were identified as being subject to current erosion processes were improved by adding three-dimensional (3D) and digital surface (DSM) models that were developed using drone acquired data. The final digital elevation model was thus filtered and improved in order to represent as accurately as possible the topographic surface.

Table 2. Nature 2000 areas

Protected area type	Name and indicative	Goal of protection	Surface (ha)
Protected area of national interest	Mestecănișul Reci and Bălțile de la Ozun Sântionlunca – RONPA0389	Flora and fauna – rare species and glacial relics	2124.7
Site of Community Importance	Ciomad Balvanyos – ROSCI0037	Five types of natural habitats	585.5
Site of Community Importance	Mestecănișul de la Reci – ROSCI0111	Seven types of natural habitats of community interest	2124.7
Site of Community Importance	Oltul Superior – ROSCI0329	Protected species (mammals, fish and invertebrates)	89.3
Site of Community Importance	Râul Negru – ROSCI0374	Protected species (mammals, amphibians and reptiles)	1892.8
Special protection area (avifauna)	Munții Bodoc Baraolt – ROSPA0082	Protected species (birds and birds with regular migration)	6267.2
Special protection area (avifauna)	Valea Râului Negru – ROSPA0147	Protected species (birds)	1892.8
Total			14977

In order to establish another defining criterion for the sensitivity analysis, the cost factor in correlation with the landforms crossed was developed, based on the types of technical solutions necessary for the implementation of the projects. Thus, each of the road alternatives were evaluated based on a cost standard used on a national scale within the General Transport Master Plan of Romania, and updated within the Investment Plan for the Development of Transport Infrastructure in 2020-2030. In terms of geomorphological factor, this approach allowed us to create a proportional hierarchical scale for transport corridors (0 to 100) (Table 3 and Table 5).

Table 3. Highway costs per km used

The dominant landform within the corridor	Estimated cost (mil. EUR. per km)
mountainous	20
mountainous – hilly	12
hilly	8
lowlands – hilly	5.5
lowlands	4.5

Thus, each transport corridor was included in one of these categories that were defined by the percentage of the dominant landform crossed by the highway alignment.

GIS software solutions were used to define the corridors, highlighting the geomorphological constraints (Dobre 2016), the impact on Natura 2000 sites (Morelli et al. 2014; van Bohemen & van de Laak 2003), determining the lengths of the strategic level corridors and the estimated costs.

The spatial analysis was conducted in the ArcGIS suite, with additional use of Agisoft Metashape for modeling drone three dimensional and imagery data. For statistical analyses, weighted calculations and modeling the sensitivity matrix, Microsoft Excel was employed, using GIS extracted data.

2.1. Area of application

The Brașov - Bacău highway project (which includes the analyzed sector Târgu Secuiesc - Onești) is part of the TEN-T Comprehensive (Fig. 3) network and is included in both the General Transport Master Plan of Romania as well as in the Investment Plan for the Development of Transport Infrastructure in 2020-2030, the most important strategic programmatic documents in Romania. TEN-T Comprehensive networks provide connections to the Core network, namely TEN-T Core which connects all regions of the European Union. This highway sector is one of the six Transcarpathian highway sectors most important for Romania's development, namely Târgu Mureș - Iași, Brașov - Bacău, Ploiești - Brașov, Pitești - Sibiu. According to the Investment Plan for the Development of Transport Infrastructure in 2020-2030, the Brașov - Bacău highway will be operational by the end of 2030.

Fig. 3. TEN-T Network in Romania and neighboring countries

In this case, the Sibiu - Brașov - Bacău highway connects two of the most important TEN-T Core corridors within Romania:
1. The Transcarpathian Corridor: Constanța (the largest port on the Black Sea) - Bucharest - Pitești - Sibiu - Arad - Nădlac (border with Hungary) with,
2. Siretului Road Corridor: Giurgiu (border with Bulgaria) - Bucharest - Ploiești - Bacău - Suceava - Siret (border with Ukraine).

The current road connection between Brașov and Bacău is outdated in terms of traffic volumes, has geometries in longitudinal and transverse profile imposed by relief, which restrict traffic speeds and have a negative impact on traffic safety. It also generates significant amounts of CO_2 emissions.

While the Brașov - Bacău highway is expected to take over the traffic from the national road 11 (DN11), it will also generate new trips due to shorter travel times and less traffic delays.

2.2. The highway project at regional level

The Brașov - Bacău highway project connects with the A3 motorway sector (Sibiu - Brașov) within the vicinity of the town of Hărman, with further crossing territorial administrative units of Sfântu Gheorghe, Târgu Secuiesc, Onești and Bacău. In the area of the city of Bacău, it connects with the A7 Bucharest-Buzău - Bacău - Suceava - Siret highway.

Regarding the relief configuration, we can distinguish three distinct units, well individualized by their geological and geomorphological characteristics and particularities, as follows:

- The depression sector – Brașov tectonic depression (with flat or slightly inclined plain characteristics);
- The mountain sector – Eastern Carpathians, sector formed by Nemira Peak (with high slopes and intense riverbed and slope geomorphological processes);
- The Subcarpathian sector – with valley compartments and depression but also with slopes intensely affected by gravitational processes.

As shown above, the transport corridors are presented on a systemic scale of connectivity in strategic documents, but for the sustainable establishment of a corridor, detailed multidisciplinary analyses are needed in order to highlight as accurately as possible the areas of favorability and restrictiveness for project implementation.

Thus, in order to establish a working methodology adapted to the current requirements of the General Transport Master Plan of Romania, four corridors were established, as alternatives, component parts of the future Brașov - Bacău highway for Tg. Secuiesc - Onești sector (Fig. 4).

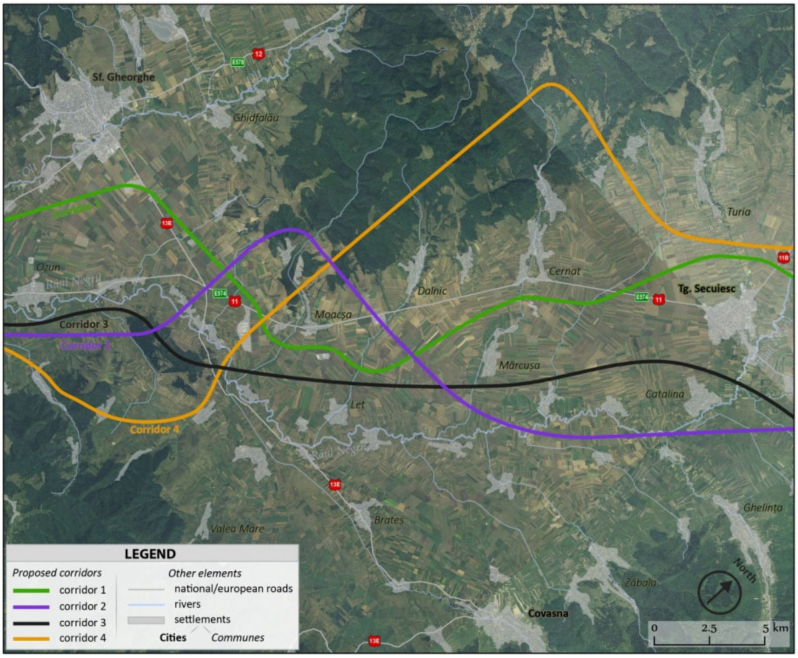

Fig. 4. Proposed highway corridors

The four routes meet the criteria for the construction of highways in Romania (Ind. PD 192-2002), among them listing: the lack of level intersections with other roads, slopes of maximum 5° and radius of curvature that allow traffic speeds of 130 km/h or at least 80 km/h in special conditions.

The four corridors were drawn up in such a way as to highlight the benefits of the sensitivity analysis in choosing an optimal road transport corridor in accordance with the beneficiary's policies and interests. For example, corridor 1 has no impact on Natura 2000 sites, no geomorphological constraints, but due to the sinuous nature imposed by avoiding these unfavorable areas, the length of the corridor is much longer with direct implications on the final cost of implementation and subsequent operating costs. In contrast, corridor 3, with an impact on Natura 2000 sites, but a shorter length by about 4 km, has financial benefits related to the construction and management of the motorway sector.

The four route alternatives were made following the digital modeling of the natural and anthropogenic factors that ensure the support of the proposed road infrastructure. In order to better present the analysis performed, each of the four alternatives has various characteristics related to the impact on Natura 2000 sites, cost standards and geomorphological features (Fig. 5, Table 4 and Table 5):

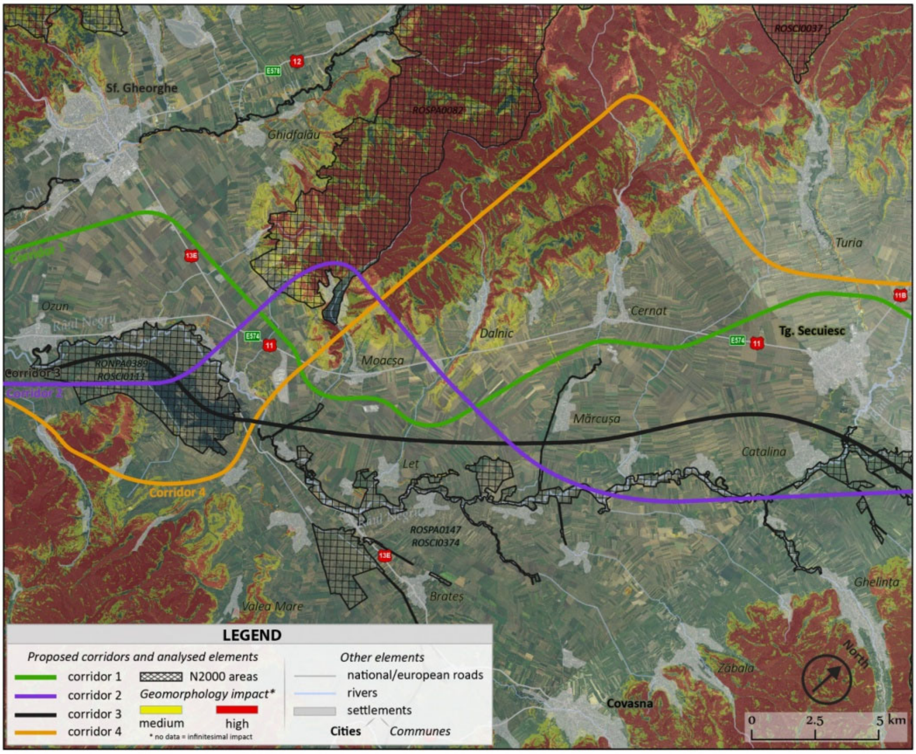

Fig. 5. Proposed highway corridors and analyzed elements

- Corridor 1 (C1) – length of 41.2 km, has no impact on Natura 2000 sites, from a geomorphological point of view crosses stable areas with slopes below 5% and altitudes of approximately 500 m a.s.l.;
- Corridor 2 (C2) – length of 41.1 km, has an impact on Natura 2000 sites, from a geomorphological point of view, it crosses mostly stable areas with slopes below 5% and altitudes of approximately 500 m, but also crosses certain areas with slopes over 10% and altitudes over 600 m. In terms of impact on Natura 2000 sites, out of the total area of protected areas in the working area of 14309.4 ha, corridor 2 affects approximately 10.6% of them, ie 1516.3 ha or 13.4 linear km;
- Corridor 3 (C3) – length of 37.6 km, has an impact on Natura 2000 sites, from a geomorphological point of view, crosses stable areas with slopes of less than 5% and altitudes of approximately 500 m. Regarding the Natura 2000 sites, from the total area of protected areas in the working area of 14309.4 ha, corridor 3 affects approximately 9.9% of them, ie 1416.3 ha or 11 linear km;

- Corridor 4 (C4) – length of 46.2 km, has no impact on Natura 2000 sites, from a geomorphological point of view it crosses mostly unstable areas with slopes of over 15% and altitudes of over 800 m.

Table 4. Proposed highway corridors (summary)

	Impact N2000	Geomorphological factor	Length/cost/cost per km
C1	No	Without constrains	41.2 km/226.7 m. EUR/5.5 m. EUR
C2	Yes	Crosses restrictive areas	41.1 km/329.1 m. EUR/8 m. EUR
C3	Yes	Without constrains	37.6 km/169.1 m. EUR/4.5 m. EUR
C4	No	Crosses restrictive areas	46.2 km/554.3 m. EUR/12 m. EUR

Table 5. Proposed highway corridors (score)

	Environmental criterion score (EC)	Geomorphological criterion and cost score (GCC)
C1	100	80
C2	60	50
C3	80	100
C4	100	30

For calculation of the weighted score of the analyzed corridors for the three selected scenarios, the weighted average was employed.

Scenario 1 (S1 – equal weight) – in this scenario, each element of the analysis contributes equally to the final average.

$$S1 = (EC \times 1) + (GCC \times 1) / (1+1)$$

Scenario 2 (S2 – great importance of the environmental criterion) – in this scenario, the environmental criterion (EC) data set contributes five times more to the final average than the geomorphological criterion and cost data (GCC).

$$S2 = (EC \times 5) + (GCC \times 1) / (5+1)$$

Scenario 3 (S3 – great importance for the geomorphological criterion and cost) – in this scenario, the data series on the geomorphological criterion and cost (CGC) contributes five times more to the final average than the data series on the environmental criterion (CM).

$$S3 = (EC \times 1) + (GCC \times 5) / (5+1)$$

Table 6. Proposed highway corridors (score based on scenario)

	Equal weight (S1)	Environmental criterion weight (S2)	Geomorphological criterion and cost weight (S3)
C1	90.0	96.7	83.3
C2	55.0	58.3	51.7
C3	90.0	83.3	96.7
C4	65.0	88.3	41.7

3. Results

This tool has proven to be a powerful element in the decision-making process, especially in this context where environmental impact and investment costs in relation to the benefits of implementing a major transport infrastructure project are greatly emphasized.

The results of the sensitivity analysis are illustrated in Figure 6 and Table 7.

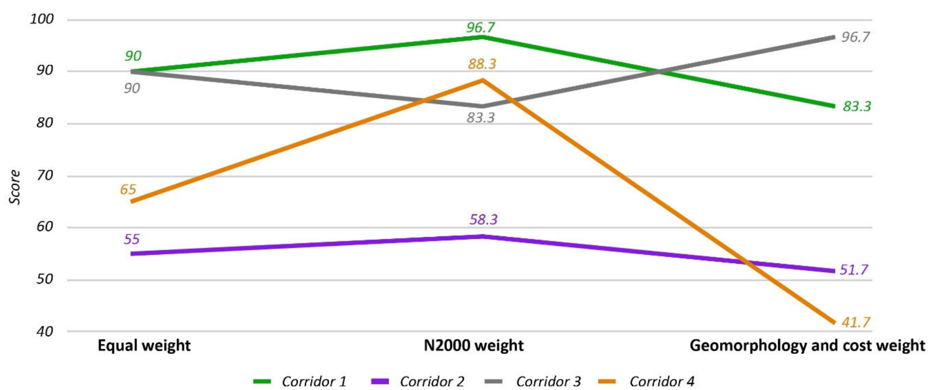

Fig. 6. Sensitivity analysis results (graph)

Table 7. Sensitivity analysis results

Ranking	Equal weight (S1)	Environmental criterion weight (S2)	Geomorphological criterion and cost weight (S3)
1	**Corridor 1** **Corridor 3**	**Corridor 1**	**Corridor 3**
2	**Corridor 4**	**Corridor 4**	**Corridor 1**
3	**Corridor 2**	**Corridor 3**	**Corridor 2**
4	**n/a**	**Corridor 2**	**Corridor 4**

3.1. Scenario analysis

Scenario 1 (S1) – Equal weight. In this scenario, the analysis criteria for the four transport corridors were treated as a unit. Thus, following the ranking according to the score obtained after quantifying the impact on Natura 2000 sites and the geomorphological and cost factor, corridor 1 and 3 are equal to 90 points. Corridor 4 scored 65 points and corridor 2 scored 55 points. The low score of corridor 4 (65 points) results from the high estimated cost of its implementation, crossing complex and geomorphologically unstable areas that generate an estimated cost of 554.3 million euros (12 million euros/km). The score of corridor 2 of only 55 points is caused by the fact that it has the greatest impact on Natura 2000 sites and by the fact that it crosses complex and geomorphologically unstable areas, resulting in an estimated cost of 329.1 mil. euro (8 mil. euro / km).

Scenario 2 (S2) – High weight for environmental criteria. In this scenario, the environmental data series contributes five times more in the final score than the geomorphological and cost data series. Thus, following the ranking according to the score obtained after quantifying the impact on Natura 2000 sites and the geomorphological and cost factor, corridor 1 got the best score, with 96.7 points. This score is due to the fact that this corridor has no impact on Natura 2000 sites, but in order to avoid the intersection with protected natural areas, the corridor is longer (41.2 km) and crosses lowland and hill areas at an estimated cost of 5.5 million euros. / km (lower score for the geomorphological and cost criterion). Corridor 4 is in 2nd place with a final score of 88.3 points, due to the fact that it does not cross protected natural areas. However, it was de-scored within the geomorphological and cost criteria because it crosses the most difficult sector from a geomorphological point of view and has the longest length (46.2 km) and implicitly the highest cost, of 554.3 million euros (12 million. euro / km). Corridor 3 ranks 3rd with a score of 83.3 points, a consequence of the intersection with protected natural areas (ROSPA 0389, ROSCI 0111, ROSCI 0374, ROSPA 0147), even if it is the shortest (37.6 km) and represents the corridor with the lowest cost among those analyzed (estimated cost of 169.1 million euros - 4.5 million euros / km). Corridor 2 is also in this scenario in the last place, as it crosses protected natural areas (ROSPA 0389, ROSCI 0111, ROSPA 0082, ROSCI 0374, ROSPA 0147) and difficult geomorphological areas (hilly areas affected by current geomorphological processes).

Scenario 3 (S3) – High weight for geomorphological criterion and cost. In this scenario, the geomorphological and cost data series contributes five times more to the final average than the environmental data set. Thus, following the ranking, depending on the score obtained after quantifying the impact of the geomorphological / cost factor and Natura 2000 sites, corridor 3 got the highest score of 96.7 points. This score is due to the fact that this corridor does not cross restrictive areas from a geomorphological point of view, being proposed only in lowland areas. This corridor is also the shortest, with a length of 37.6 km, at an estimated cost of 169.1 million euros (4.5 million euros/km). However, the corridor has a larger impact on Natura 2000 sites. In 2nd place there is corridor 1 with a score of 83.3 points. This score is due to the fact that in order to avoid protected natural areas, the corridor is longer (41.2 km) and crosses the plain and hill areas at an estimated cost of 5.5 million euro / km, which ultimately resulted in a lower score for the geomorphological criterion and cost. Corridor 2 is in the 3rd place with a score of 51.7 points, due to the fact that it crosses protected natural areas and difficult geomorphological areas (hilly areas) which imposed an estimated cost of 329.1 million euros and 8 million euros/km. Corridor 4 shows the largest oscillation among the three analyzed scenarios, now being positioned in the last place with a score of 41.7 points. Although it does not cross Natura 2000 sites, it crosses the most difficult sector in terms of relief and has the longest length (46.2 km), implicitly the highest cost, of 554.3 million euros and 12 million euros / km.

4. Disscusion

According to the results, it is clear that in the context of the current environmental policy promoted and supported by the European Commission, through the new Green Deal concept, Scenario 2 (S2) is the best option for the implementation of infrastructure projects. This scenario envisages giving a significant weight to the environmental component and less to the geological or geomorphological ones, resulting in higher costs.

Thus, the ranking of projects resulting from the use of Scenario 2 best corresponds to the current context in which the design, construction and operation of infrastructure projects should be done in an ecologically sustainable manner, in conformity with the environmental regulations and protected areas, even though it results in higher construction and operational costs. Scenarios 1 and 3 are therefore favorable for minor infrastructure projects, in which the environmental component has a lower weight. It has been proven that a GIS based sensitivity analysis is a necessity in choosing the route variant that corresponds to the real connectivity needs. This method, as part of a decision-making process, can be applied by the beneficiary of large transport infrastructure projects for the sustainable implementation of highway projects, representing a rigorous assessment of land and all components that have a direct influence on the design, construction and operation of such project. As part of the multi-criteria analysis, the proposed and tested methodology can thus be applied to both road and rail infrastructure projects.

One of the important goals achieved through this approach was obtaining objective, undisputed results, which through an efficient communication, could be generally accepted by the local communities involved, media and non-governmental organizations.

This methodology proves that it can be an asset in strategic planning which can be applied in other European member states as well, an aspect emphasized by JASPERS Romania office during technical meetings.

5. Conclusions

This paper represents an analysis model which provides geographically substantiated quantitative solutions. This new approach can be introduced as a mandatory study in the legislation for the analysis of route / corridor alternatives that are to be implemented. The analysis aims to establish a route of a sector of Brașov - Bacău highway, which should meet the technical, environmental and cost criteria. In this context, four highway corridors with different, well-individualized physical-geographical features were established and analyzed, which were differentiated based on a score function. The three evaluated criteria took into account the spatial relationship between corridors and protected areas, geomorphological forms and processes and estimated costs. The differentiation of the four alternative routes was made based on the resulting score which had three types of weights (equal weights, high weight for the environmental criterion, high weight for the geomorphological and cost criterion). The three scenarios highlight the hierarchical variations of the corridors according to the assigned criteria and weights. The study can be used at governmental or regional decision-making level because it provides objective information on which scientifically substantiated choices can be made. For an even greater refinement of the results, other data sets can be introduced in the working methodology, such as the disposition of utilities, flood risk, commercial, residential or industrial areas.

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