Assessing Infrastructures Alternatives: The Implementation of a Fuzzy Analytic Hierarchy Process (F-AHP)

Maria Cerreta(✉), Giuliano Poli, and Maria Somma

Department of Architecture, University of Naples Federico II, via Toledo 402, Naples, Italy
{cerreta,giuliano.poli,maria.somma}@unina.it

Abstract. The conventional approach that often dominated spatial planning has prioritized urban expansion and new urban transport infrastructure without fully considering environmental aspects. While this has generated new urban models and economies, it has also significantly impacted the territory and landscape negatively. The construction of road infrastructure can improve the sustainability of a city from the point of view of connectivity between places. However, it also generates a disruption of the landscape with a consequent loss of ecosystem services. The case study concerns the evaluation of the preferable alternative, between two proposals, for the construction of a new road called the Teramo-Mare, connecting the Abruzzo hinterland with the Adriatic coast. The methodological approach investigates the scientific background in landscape assessment related to the construction of road infrastructures. By modelling the Multi-Criteria Decision Analysis (MCDA) with Fuzzy set theory and the Fuzzy Analytic Hierarchy Process (F-AHP) an evaluation method is tested to face the choice of the preferable alternative. The study provides an initial review of the scientific reference landscape and identifying criteria to help evaluate the option that has the least impact on the landscape and ecological system.

Keywords: Spatial indicators · Sustainability indicators · GIS-based evaluation method · Spatial road analysis · Landscape impacts

1 Introduction

The Council of Europe Landscape Convention - as amended by the 2016 Protocol - provided a landscape's definition referred to as: "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors". Furthermore, it emphasized that the planning activities must include forward-looking strategies to restore or create new landscapes in a sustainability pathway [1].

The Convention has highlighted the landscape's character as a whole of material and immaterial factors which are strictly interrelated, dynamic, and variable, and whose understanding hybrid and integrated assessment methods are needed [2].

In this perspective, the Landscape Character Assessment (LCA) [3] (https://www.nature.scot/) attempted to provide stakeholders, practitioners, and academics with guidelines and tools to cope with the complexity, recognizing that each landscape is unique,

O. Gervasi et al. (Eds.): ICCSA 2021, LNCS 12955, pp. 504–516, 2021.
https://doi.org/10.1007/978-3-030-87007-2_36

and the landscape pattern variation can be detected and spatially represented and assessed [4].

The conventional approach dominating spatial planning has focused on the urban sprawl and the construction of new urban transport infrastructures for a long time, without fully including environmental aspects [5].

Geographical criteria generally considered in road alignment problems exclude the broadest landscape components prioritizing technical factors to the detriment of ecological, social, and aesthetic dimensions [6]. While this has generated new urban patterns and economies, it has also significantly impacted the territory and landscape [6]. On the one hand, new road infrastructures boost cities' sustainability regarding connectivity between places. On the other hand, roads generate a landscape break with a consequent loss of ecosystem services [7].

In England, the LCA methodology and its procedures have been matching up for several years with local authority plans and strategies, land use planning and land management, or other assessment tools, e.g., Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) [3].

The primary LCA potential is inherent in providing evidence at an in-depth scale to inform decisions better using georeferenced data and mapping with a holistic approach. Moreover, its integration with GIS-based analysis is overwhelming when decisional agents examine maps before eliciting their preferences [8].

Visual maps or spatial indicators enhance the knowledge of complex phenomena linked to the landscape's characters. Indeed, the decision-making benefits from the spatial representation making geomorphological criteria, physical landscape characters, immaterial components, and constraints more explicit.

Significant limitations can refer to data availability and detection, which are time-consuming, expensive, and hard-to-build. In addition, including the broad scale in the evaluation - by modelling choice problems in a GIS environment - can incur extreme generalization of the landscape's features. Furthermore, site-specific surveys and epistemic knowledge can balance this problem [9].

The twofold research's purpose addressed to:

- Test a valuation procedure that includes uncertainty related to multiple experts' judgement into a spatial decision-making framework through Multi-Criteria Decision Analysis (MCDA).
- Experiment with an easy consulting questionnaire [10] to gather experts' relative preferences and derive a consistent judgment matrix with F-AHP.

The ambition is to expand the obtained valuation model from a discrete problem (MADM) to an ongoing problem (MODM) in a GIS environment.

The case study to test the proposed methodology is related to four Municipalities in Abruzzo (Italy) to construct new road alignments boosting connectivity among inner areas and the coastal zones.

2 The Scientific Landscape

For the last thirty years, the authors have aimed to find relationships between road infrastructure planning and landscape in the scientific literature. Connecting terms were searched in the scientific database SCOPUS using logical operators AND/OR with the following string: ("landscape" OR "landscapes") AND ("roads" OR "road" OR "highway" OR "road alignment" OR "highway alignment") AND ("valuation" OR "evaluation" OR "assessment") AND ("urban planning").

Four clusters made by the most recurring terms emerged within the thematic literature through the scientific landscape method [11].

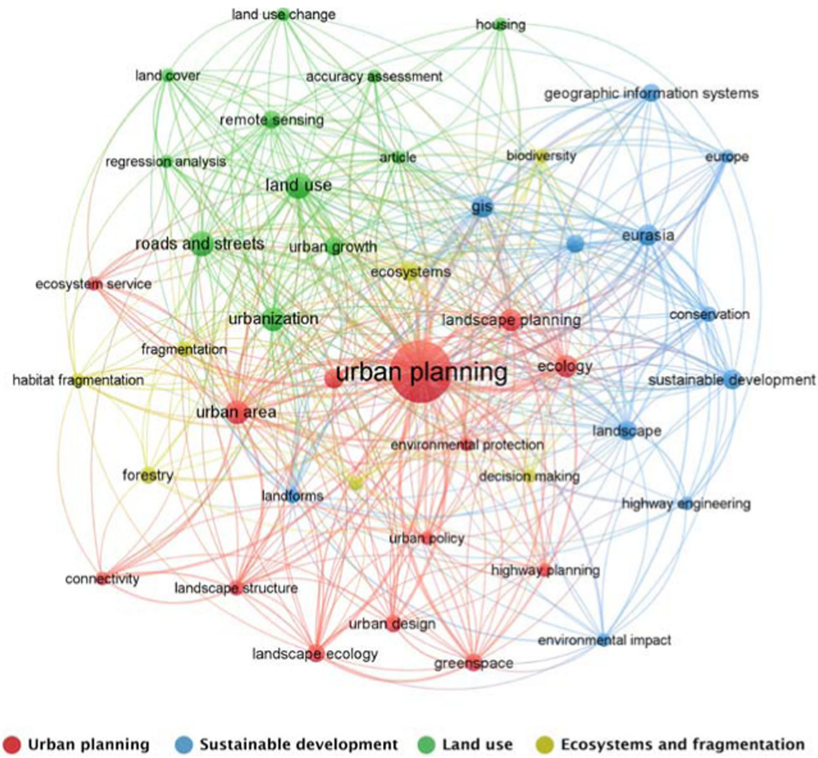

Fig. 1. The scientific landscape. Source: Authors' elaboration

These clusters refer to:

1) Urban planning;
2) Sustainable development;
3) Land use;
4) Ecosystem and fragmentation.

It has noticed the centrality of urban planning studies fostering cross-cutting issues and the multidisciplinary (Fig. 1).

Indeed, some authors remarked that the leading cause of land use and land cover change is urbanization [12, 13]. However, it is unrealistic to monitor and analyze urbanization's ecological and socio-economic effects [14], without a comprehensive understanding of how the city is changing.

A road has other lesser-known consequences on ecosystems, and more crucially, on the countryside dynamics of those places that it crosses, not just the acknowledged effects of transport like pollution, noise. In a relatively short period, these disturbances might lead to significant changes [15].

Numerous studies have addressed to understand the relationship between transportation and land use. The building of new transportation infrastructure would inevitably affect land development. Highways have essential social and economic purposes, but they facilitate ecosystem disruption through fragmentation, noise pollution, habitat loss, and species extinction through landscape segmentation and edge effects [16–21]. Because of the vast current and proposed road networks [22–24], it is more important than ever to consider the spatial and temporal distribution of these environmental impacts generated by highways [25].

About any expenditure on the road has benefited the national economy. However, this economic viewpoint is insufficient for examining all a transportation infrastructure's spatial impact, especially those linked to the transition it has wrought on the landscape over time. There is an inherent interplay between urban space and human-made development, such as unregulated urban sprawl and the proliferation of infrastructure. These elements must be understood from an environmental, economic, and social standpoint [26]. Several surveys have been addressed to determine the effects of highway building on the atmosphere and landscape, and social life. About any expenditure on the road has benefited the national economy. However, this economic viewpoint is insufficient for examining all a transportation infrastructure's spatial impact, especially those linked to the transition it has wrought on the landscape over time. The issues related to the "Ecosystem and fragmentation" cluster highlighted that the highway building has a much-varied landscape and ecological consequences [16, 20, 27] inadequately quantified and recognized [28]. For example, the influence distance or path-effect zone - the distance outward from a road where significant ecological effects occur [16] - is commonly used to measure road building and usage [27, 29, 30].

3 Materials and Methods

The research's purpose was to test a methodology for solving a choice problem linked to new road alignments in the Abruzzo region (Italy). Two alternatives were assessed concerning six geographical criteria: Naturality, Fragmentation, Urban density, Historicity, Proximity to urban areas, and Accessibility.

The goal concerns a discrete problem to be solved with Multi-Attribute Decision Making since environmental, socio-cultural, and technical performances related to two proposed road alignments have to be assessed by an experts group. Therefore, a three-step methodology has been structured to achieve a ranking for supporting the best-fit alternative choice (Fig. 2).

The first step is inherent to the knowledge and criteria related to the alternatives' features were set. The second step concerns the MCDA modelling with the Fuzzy set

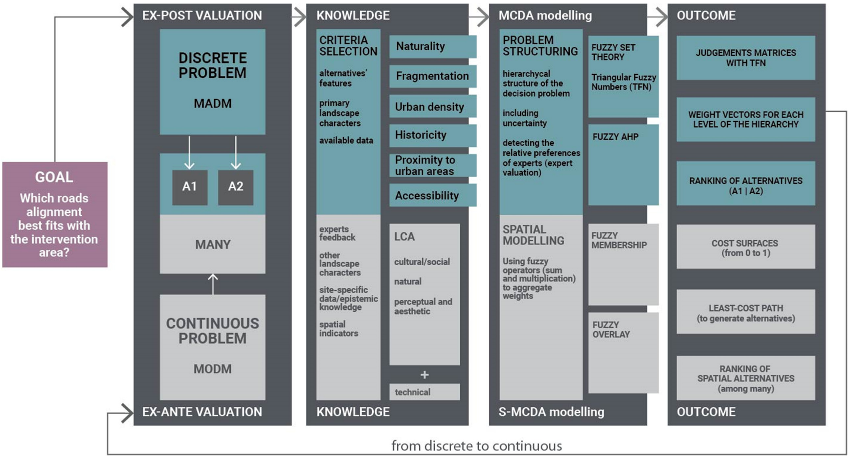

Fig. 2. A methodological workflow for managing a choice problem linked to new road alignments. Source: Authors' elaboration.

theory and the Fuzzy Analytic Hierarchy Process (F-AHP). Finally, the last step is related to the outcome that has determined the weight vectors for each hierarchy level and the final ranking of the alternatives.

3.1 The Case Study

The study area is in the northern of Abruzzo (Italy), east of the Teramo city, connecting the S.S. 80 with the S.S.16. The municipalities of Notaresco, Roseto degli Abruzzi, Mosciano Sant'Angelo, and Giulianova are involved in the building of the new highway, which aims to enhance connectivity between the Giulianova coast served by S.S. 16 "Adriatica", the Teramo region served by S.S. 80 "Raccordo di Teramo" and the major established infrastructures (A14 highway - Mosciano Sant'Angelo junction, Teramo-Giulianova railway line, Mosciano station) (Fig. 3).

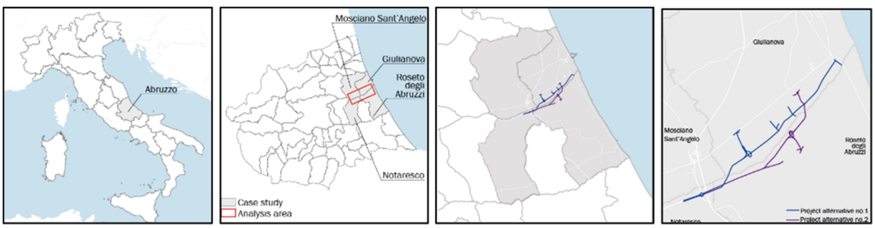

Fig. 3. The case study's geographical frame. In order: Italy; Abruzzo Region, the municipalies of Giulianova, Mosciano Sant'Angelo, Roseto degli Abruzzi, Notaresco; the case study: two hightways alternatives. Source: Authors' Elaboration

In the area of interest are located the main strategic roads:

- The SS. 80 “del Gran Sasso di Italia” that connects Teramo to Giulianova;
- The S.S. 80 Raccordo di Teramo connects the A24 and the A14 near the junction of Mosciano Sant’Angelo.
- The railway line Teramo-Giulianova connects to the Adriatic railway ridge.

These conditions have favoured the development of productive settlements. In this area, the Apennine chain reaches its maximum proximity to the Adriatic Sea.

The narrow alluvial plain characterizes the area at the bottom of the “Tordino” River valley, one of the five watercourses of piedmont origin that flow entirely within the administrative boundaries of Teramo’s province. The project explicitly concerns the valley’s final stretch from Mosciano S. Angelo (about 7 km from the mouth) to Cologna Marina (about 800 m from the mouth).

The fundamental data needed to frame and describe the intervention area’s environmental, socio-cultural, and technical aspects were assumed from the most widely used urban and territorial planning tools, the ISTAT censuses, open regional and satellite data series (Copernicus).

The new road represents an alternative to the historical S.S. 80 of “Gran Sasso d’Italia”, which has taken on the characteristics of a “local” road system serving the production and residential areas. The latter has led to a decline in the level of service typical of a secondary suburban road system due to the widespread presence of accesses, junctions, and traffic lights, which significantly reduce the level of service to users in terms of journey times and road safety.

The construction of the new Teramo - Mare section aimed to decongest the area of interest, linking them to the flourishing settlements in the “Colleranesco” area and the neighbouring regions, which are already putting a strain on the well-established S.S. 80 infrastructure, which no longer meets the efficiency criteria for current vehicle flows. Furthermore, there is a need to connect the inland areas with the areas along the coast. The inland areas are widespread economic obsolescence due to their location (poor accessibility that makes them marginal) and the prevalence of backward economic sectors compared to modern ones. In these terms, the economy is not self-propelling but in need of exogenous support [31–33].

3.2 Knowledge Phase

The knowledge phase has allowed the study area knowledge to be performed by defining natural, cultural, and technical criteria. Thus, the elaboration of spatial criteria maps has favoured consulting with stakeholders. The LCA [3] defined these criteria were implemented by technical criteria selected through interviews with ten experts and linked mainly to transport engineering. The interviewed experts are a project manager, a safety engineer, three construction engineers, two architects, an urban planner, a system engineer, and a professor of environmental appraisal. The spatial representation of the natural, cultural, and technical dimensions follow. As shown in Fig. 4, spatial and non-spatial data used to analyze the natural dimension come from the geoportal of the Abruzzo

Region (http://geoportale.regione.abruzzo.it) and the Fiume Sangro Regional and Interregional Basin Authority (http://autoritabacini.regione.abruzzo.it). These maps merged with the database provided by the Copernicus Land Monitoring Service portal (http://land.copernicus.eu). For this dimension, the naturalness (C1) and fragmentation (C2) criteria were analyzed.

3.2.1 Natural Dimension

The naturalness criterion was defined by reprocessing raw data from the Corine Land Cover, the Abruzzo Region Landscape Plan and visual analysis through virtual navigation in Google Earth. This criterion defines a mapping where forest land, cultivated land, grasslands, wetlands, dunes, beaches and riparian areas can be distinguished.

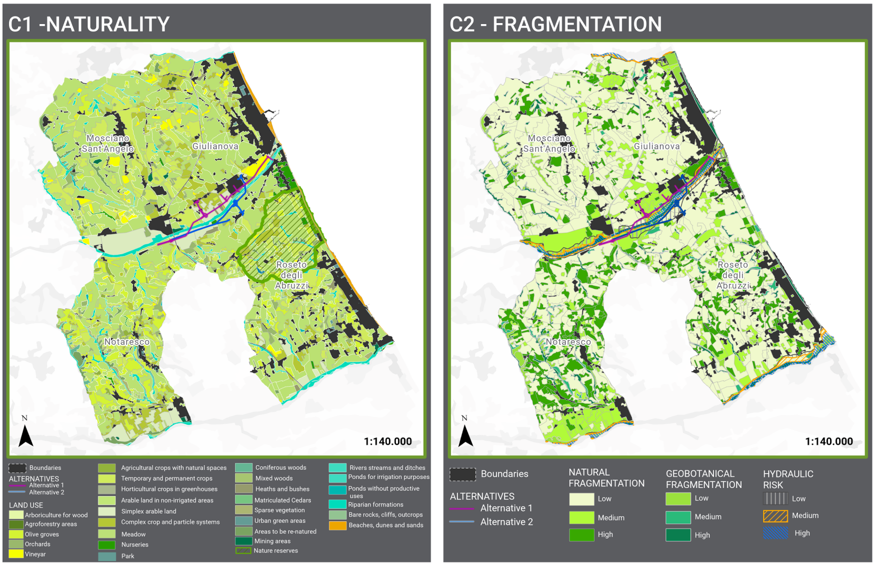

Fig. 4. Natural dimension maps with the analysis of Naturality (C1) and Fragmentation (C2) criteria. Source: Authors' Elaboration

Both proposed alternatives fall within predominantly agricultural areas, simple alternating crops, and in non-irrigated areas with permanent crops with another predominance of vineyards north of the Tordino's river.

The analysis related to fragmentation represents one of the main components of land research [34]. For the fragmentation criterion, the degree of naturalistic, geobotanical and hydraulic risk fragmentation was analyzed. In the initial stretch, which is common to the two project routes, the areas crossed partly present a low level of naturalistic fragmentation (in these areas, there are arable crops in non-irrigated areas and/or temporary crops associated with permanent crops). There is a medium level of fragmentation (simple arable crops, forest formations with prevalent fruit production, other tree crops, permanent meadows, complex crop and plot systems and agroforestry areas alternate) in the other part. The final stretch, which is common to both solutions, is characterized by areas of high naturalistic fragmentation. In this section, portions of urbanized land are also intercepted.

In the area covered by alternative no. 1, there is medium. In the stretch of the Tordino's river, there is high naturalistic fragmentation about geobotanical aspects.

For the area south of the Tordino, where alternative No 2 locates, there is a medium level of naturalistic fragmentation, which tends to become low as it proceeds towards the coast, except for the stretch where the Tordino's river crosses. The alternative also does not intercept areas of geobotanical value.

In addition, both alternatives were designed outside the boundary of areas protected by law from hydrogeological constraint, except where they cross the River Tordino or some of its tributaries (Fosso Mustaccio, Fosso Cavone and Fosso Corno).

3.2.2 Socio-Cultural Dimension

The authors compared the database for the socio-cultural dimension provided by the Abruzzo Region was with Open Street Map (OSM).

The four municipalities involved in the intervention have a high concentration of settlements of high historical interest (C3 – Historicity). The buffer zone where the two alternatives fall does not intercept any works of historical value (Fig. 5, C3). The design of the junction would connect the historical heritage in the area, which is currently challenging to access. The infrastructure with its various exits and entrances will connect to local roads directly from the Adriatic and Teramo motorways.

The population data were fundamental in defining the population density criterion.

The data came from the latest population census provided by ISTAT and dating from 2011considering that the work's design process was started before 2011.

In 2011, a very high percentage of urban density (Fig. 5, C4) was recorded in the coastal municipalities, while inland municipalities recorded a lower population density.

In the buffer zone comprising the two project alternatives, there is a minimum population density due to industrial areas along the Tordino riverside and active and disused quarries, which have limited the appearance of new urbanization over time, especially housing (Fig. 5).

Alternative No. 1 will have an exit at Colleranesco and the industrial area. The population density here is medium. It is also foreseen rejoining with the present SS.16 Adriatica. For alternative No. 2, an exit is foreseen at Coste Lanciano (Roseto Degli Abruzzi) and a second one at the industrial area of Colleranesco (Giulianova).

3.2.3 Technical Dimension

The provided technical criteria maps help to standardize the landscape characteristics with the transport engineering factors. In addition, criteria related to proximity to urban areas (C5) and accessibility (C6) have been designed to evaluate the best-fit alternative. The road infrastructure database was provided by OSM, Copernicus and the Abruzzo Region territorial database.

Both alternatives, within a radius of 2 km, are close to the main urban settlements. In particular, Alternative No. 1 is well connected to all the main commercial and tertiary

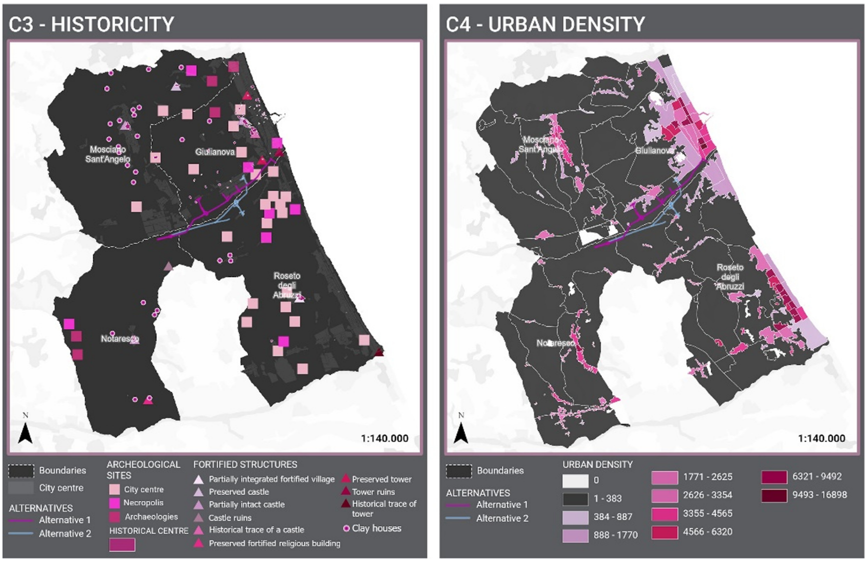

Fig. 5. Cultural dimension maps with the analysis of Historicity (C3) and Urban density (C4) criteria. Source: Authors' Elaboration

services and connects to the residential settlements along the coast. On the other hand, alternative No. 2 is detached from the leading manufacturers and residential areas (Fig. 6, Image C5). The accessibility criterion (Fig. 6, Image C6) involved the analysis of rails and roads. The central railway stops falling within the study area were identified. In particular, the two alternatives are much closer to the Mosciano Sant'Angelo stop, located to the north and parallel to the initial section of the two proposed alternatives. In addition, the study area in which the two project alternatives fall is crossed by infrastructures that are mainly local, alternating small roads and pedestrian roads). The only motorway (Autostrada Adriatica) intercepts the two alternatives in the initial section of the project. In the final section, from the hinterland to the coast, the two alternatives intercept the highway 16 Adriatica.

3.3 The MCDA Modelling

The operational steps of MCDA allowed data mapping to be used as explicitly spatial criteria. Indeed, the spatial criteria maps were provided to the experts to support them in answering an objective questionnaire. When the problem's hierarchical structure has been defined, the authors asked experts to attribute a score on a 1–9 scale at each level. Three levels of the AHP method are the following:

- The first level, which is related to natural, cultural and technical dimensions;
- The second level, which includes the six criteria (Naturality, Fragmentation, Urban density, Historicity, Proximity to urban areas, and Accessibility),
- The third level is related to the two alternatives.

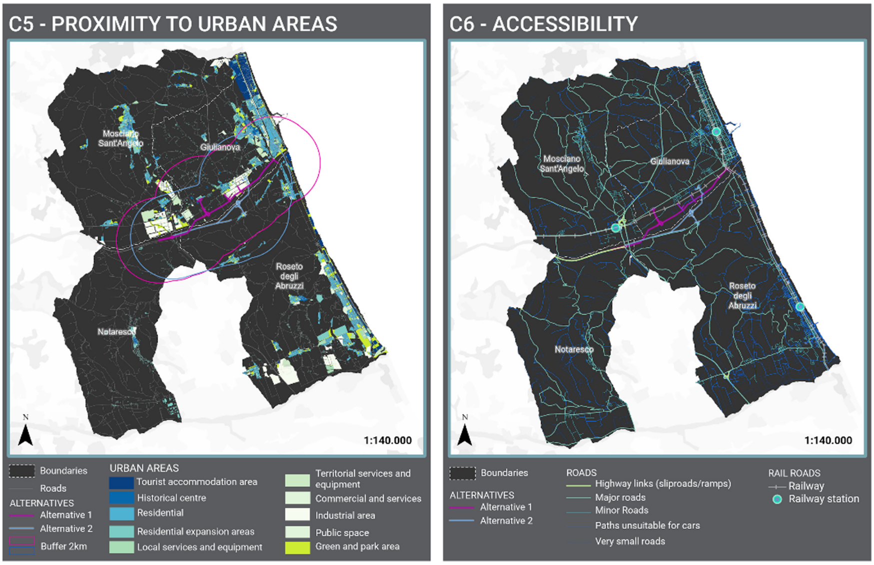

Fig. 6. Technical dimension maps with the analysis of Proximity to urban areas (C5) and Accessibility (C6) criteria. Source: Authors' Elaboration

F-AHP has allowed to include uncertainty in the evaluation, and it has been performed through the following steps, which are presented briefly:

- A range number with the lower and the highest score by the survey has been determined;
- A pairwise comparison matrix with the ratio of two-interval numbers has been shaped;
- A consistency check of the most likely crisp number representing this ratio has been calculated;
- A fuzzy judgment matrix for each hierarchy level has been obtained;
- The Fuzzy Synthetic Extent by Chang 2008 [18] has been calculated to produce the triangular fuzzy memberships;
- A likely value within the fuzzy membership was excerpted;
- The normalized weight vector for each hierarchy level has produced the ranking of the alternatives.

For more details on the operational steps, see Lyu et al. 2020 [10].

4 Outcomes

The operational steps briefly mentioned in Sect. 3.3 were fundamental in defining the preferred alternative. Figure 7 clarifies which of the two alternatives is preferable.

The results were obtained by comparing the different matrices obtained through the questionnaire provided to the experts. In this case, the coefficient matrix was defined by comparing the alternatives to the individual criteria (C1 to C6).

COEFFICIENT MATRIX OF PAIRWISE COMPARISON FOR ALTERNATIVES (Ai) TO C1-C6 CRITERIA								
	C1	C2	C3	C4	C5	C6	Normal weights	
Normal weight	0,125	0,181	0,192	0,185	0,160	0,155		
A1	0,7000224997	0,667896679	0,6363413237	0,332103321	0,6363413237	0,332103321	0,5451943748	THE BEST FIT ALTERNATIVE
A2	0,2999775003	0,332103321	0,3636586763	0,667896679	0,3636586763	0,667896679	0,4528056252	
	1	1	1	1	1	1	1	

Fig. 7. Coefficient matrix of pairwise comparison for alternatives (Aj) to C1-C6 criteria: The best-fit alternatives. Source: Authors' Elaboration

The best-fit alternative is the A1 north of the Tordino River. This result was obtained by providing stakeholders with a single questionnaire that reduced by 50% the time usually spent on traditional questionnaires.

Moreover, during the consultation with the experts, the questionnaire appeared easy to read, intuitive and quick. It provided them with maps of the criteria described at length in the previous paragraphs, allowing them to assign a weight in a completely objective manner.

5 Discussion and Conclusions

The proposed MCDA has allowed a best-fit alternative of road alignment to be chosen by including six criteria (Naturality, Fragmentation, Urban density, Historicity, Proximity to urban areas, and Accessibility) within natural, socio-cultural, and technical dimensions.

The Landscape Character Assessment (LCA) was chosen as an inclusive framework to expand evaluation criteria beyond technical factors generally included in infrastructure planning.

The adopted questionnaire (from Lyu et al. 2019 [10]) aided to simplify AHP judgements attribution by avoiding pairwise comparison, which is generally time-consuming and complex for Stakeholders. In addition, F-AHP allows uncertainty to be included in the weighting procedure by grasping global weights as the most likely values which experts can converge.

The computational procedures are time-consuming, complex, and error-prone, especially when the number of criteria and alternatives grows.

The feedback loop of the integrated valuations will provide decision-makers with further road alignments by shifting from a discrete problem (with a finite set of alternatives) to a multiobjective decision-making problem.

The proposed methodology will allow gathering no-spatial explicitly weights and shifting them into spatial explicitly tiers through F-AHP in a GIS environment.

The multi-group valuation within the spatial decision support systems constitutes a valuable tool for checking the transparency of preferences, which can be appropriately assimilated to objective procedures to structure more inclusive multi-stakeholder decision-making processes.

Author Contributions. Conceptualization, M.C., G.P., M.S.; methodology, G.P., M.S.; validation, M.Cerreta, G.P.; formal analysis, G.P., M.S.; investigation, M.S.; writing-original draft preparation, G.P., M.S.; writing-review and editing, M.C., G.P., M.S.; visualization, M.S.; supervision, M.C., G.P. All authors have read and agreed to the published version of the manuscript.

References

1. Council of Europe: Council of Europe Landscape Convention. Contribution to human rights, democracy and sustainable development, Strasbourg (2018)
2. Selicato, M., Torre, C.M., Trofa, G.L.: Prospect of integrate monitoring: a multidimensional approach. In: Murgante, B., et al. (eds.) ICCSA 2012. LNCS, vol. 7334, pp. 144–156. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-31075-1_11
3. Tudor, C.: An Approach to Landscape Character Assessment. Nature England, York (2014)
4. Attardi, R., Cerreta, M., Poli, G.: A collaborative multi-criteria spatial decision support system for multifunctional landscape evaluation. In: Gervasi, O., et al. (eds.) ICCSA 2015. LNCS, vol. 9157, pp. 782–797. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-21470-2_57
5. Saganeiti, L., Favale, A., Pilogallo, A., Scorza, F., Murgante, B.: Assessing urban fragmentation at regional scale using sprinkling indexes. Sustain. **10**, 3274 (2018). https://doi.org/10.3390/SU10093274
6. Torre, C.M., Selicato, M.: The support of multidimensional approaches in integrate monitoring for SEA: a case of study. Earth Syst. Dyn. **4**, 51–61 (2013). https://doi.org/10.5194/ESD-4-51-2013
7. Millennium Ecosystem Assessment: Ecosystems and Human Well-being: Synthesis Island Press Washington, DC (2005)
8. Malczewski, J., Rinner, C.: Multicriteria Decision Analysis in Geographic Information Science
9. SDSN: United Nation: Indicators and a Monitoring Framework for the Sustainable Development Goals Launching a data revolution for the SDGs. A report to the Secretary-General of the United Nations by the Leadership Council of the Sustainable Development Solutions (2015)
10. Lyu, H.-M., Sun, W.-J., Shen, S.-L., Zhou, A.-N.: Risk assessment using a new consulting process in fuzzy AHP. J. Constr. Eng. Manag. **146**, 04019112 (2020). https://doi.org/10.1061/(asce)co.1943-7862.0001757
11. van Eck, N.J., Waltman, L.: Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics **84**, 523–538 (2010). https://doi.org/10.1007/S11192-009-0146-3
12. Patra, S., Sahoo, S., Mishra, P., Mahapatra, S.C.: Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level. J. Urban Manag. **7**, 70–84 (2018). https://doi.org/10.1016/J.JUM.2018.04.006
13. Lambin, E.F., et al.: The causes of land-use and land-cover change: moving beyond the myths. Glob. Environ. Chang. **11**, 261–269 (2001). https://doi.org/10.1016/S0959-3780(01)00007-3
14. Zhu, M., Xu, J., Jiang, N., Li, J., Fan, Y.: Impacts of road corridors on urban landscape pattern: a gradient analysis with changing grain size in Shanghai. China. Landsc. Ecol. **21**, 723–734 (2006). https://doi.org/10.1007/s10980-005-5323-z
15. Ispra: L'inserimento paesaggistico delle infrastrutture stradali: Strumenti metodologici e buone pratiche di progetto (2010)
16. Klarenberg, G., MuñozCarpena, R., CampoBescós, M.A., Perz, S.G.: Highway paving in the southwestern Amazon alters long-term trends and drivers of regional vegetation dynamics. Heliyon **4**, e00721 (2018). https://doi.org/10.1016/j.heliyon.2018.e00721
17. Müller, K., Steinmeier, C., Küchler, M.: Urban growth along motorways in Switzerland. Landsc. Urban Plan. **98**, 3–12 (2010). https://doi.org/10.1016/j.landurbplan.2010.07.004
18. Wu, C.F., Lin, Y.P., Chiang, L.C., Huang, T.: Assessing highway's impacts on landscape patterns and ecosystem services: a case study in Puli Township. Taiwan. Landsc. Urban Plan. **128**, 60–71 (2014). https://doi.org/10.1016/j.landurbplan.2014.04.020

19. Creutzig, F., et al.: Transport: a roadblock to climate change mitigation? Science **350**(6263), 911–912 (2015). https://doi.org/10.1126/science.aac8033
20. Torres, A., Jaeger, J.A.G., Alonso, J.C.: Assessing large-scale wildlife responses to human infrastructure development. Proc. Natl. Acad. Sci. U. S. A. **113**, 8472–8477 (2016). https://doi.org/10.1073/pnas.1522488113
21. Shannon, G., Angeloni, L.M., Wittemyer, G., Fristrup, K.M., Crooks, K.R.: Road traffic noise modifies behaviour of a keystone species. Anim. Behav. **94**, 135–141 (2014). https://doi.org/10.1016/j.anbehav.2014.06.004
22. Ibisch, P.L.: A global map of roadless areas and their conservation status. Science **80**(354), 1423–1427 (2016). https://doi.org/10.1126/science.aaf7166
23. Southworth, J., et al.: Roads as drivers of change: trajectories across the tri-national frontier in MAP, the southwestern Amazon. Remote Sens. **3**, 1047–1066 (2011). https://doi.org/10.3390/rs3051047
24. Meijer, J.R., Huijbregts, M.A.J., Schotten, K.C.G.J., Schipper, A.M.: Global patterns of current and future road infrastructure. Environ. Res. Lett. **13**, 064006 (2018). https://doi.org/10.1088/1748-9326/aabd42
25. Brady, S.P., Richardson, J.L.: Road ecology: shifting gears toward evolutionary perspectives. Front. Ecol. Environ. **15**, 91–98 (2017). https://doi.org/10.1002/fee.1458
26. Elburz, Z., Cubukcu, K.M.: Spatial effects of transport infrastructure on regional growth: the case of Turkey. Spat. Inf. Res. **29**(1), 19–30 (2020). https://doi.org/10.1007/s41324-020-00332-y
27. Forman, R.T.T., Deblinger, R.: The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conserv. Biol. **14**(1), 36–46 (2000). https://doi.org/10.1046/j.1523-1739.2000.99088.x
28. Feng, S., et al.: Quantification of the environmental impacts of highway construction using remote sensing approach. Remote Sens. **13**, 1340 (2021). https://doi.org/10.3390/rs13071340
29. Song, Y., Jin, L., Wang, H.: Vegetation changes along the Qinghai-Tibet plateau engineering corridor since 2000 induced by climate change and human activities. Remote Sens. **10**, 95 (2018). https://doi.org/10.3390/rs10010095
30. Forman, R.T.T.: Estimate of the area affected ecologically by the road system in the United States. Conserv. Biol. **14**, 31–35 (2000). https://doi.org/10.1046/j.1523-1739.2000.99299.x
31. Fusco Girard, L.: Sviluppo sostenibile ed aree interne: quali strategie e quali valutazioni. Aestimum (2009). https://doi.org/10.13128/Aestimum-7317
32. Morano, P., Tajani, F., Anelli, D.: A decision support model for investment through the Social Impact Bonds. The case of the city of Bari (Italy). Valori e Valutazioni, 163–178 (2020)
33. Anelli, D., Sica, F.: The financial feasibility analysis of urban transformation projects: an application of a quick assessment model. In: Bevilacqua, C., Calabrò, F., Spina, L.D. (eds.) NMP 2020. SIST, vol. 178, pp. 462–474. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-48279-4_44
34. Serrano, M., Sanz, L., Puig, J., Pons, J.: Landscape fragmentation caused by the transport network in Navarra (Spain). Two-scale analysis and landscape integration assessment. Landsc. Urban Plan. **58**, 113–123 (2002). https://doi.org/10.1016/S0169-2046(01)00214-6