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IDENTIFICATION AND SEGMENTATION OF SOCIAL AND ENVIRONMENTAL CRITERIA IN MULTI-CRITERIA ANALYSIS FOR SELECTING INFRASTRUCTURE INVESTMENT OPTIONS FOR ROAD TRANSPORT

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ABSTRACT: Studies show that road investments generate both positive and negative socio-economic and environmental impacts. Social effects include improved accessibility, safety, and reduced inequality, but may also lead to increased accident rates and health concerns. A key challenge in multi-criteria analysis is the accurate identification and classification of social and environmental factors. Methods such as literature reviews, surveys, interviews, and cost-benefit analyses are used to assess these impacts and support decision-making, for example, through social impact assessments. This paper explores the difficulties in categorising various criteria as social or environmental and the implications of these classifications for evaluation processes. The authors propose a revised set of social and environmental standards for multi-criteria assessment of road investment options and examine how reclassifying certain criteria affects their relevance and validity. The study contributes to improving evaluation frameworks for infrastructure planning and supports more informed, socially aware investment decisions.

KEYWORDS: road transport, infrastructure investments, multi-criteria analysis, social impact, environmental impact

Introduction

Analysing alternative infrastructure investment options is a critical component of effective planning and implementation. A comprehensive evaluation across technical, economic, environmental, and social dimensions enables the identification of optimal solutions that maximise social benefits while minimising negative environmental impacts. To ensure reliable outcomes, appropriate analytical methods must be applied, and all relevant decision-making criteria should be taken into account during the assessment process.

The analyses presented in this paper are an extract from a project concerning the development of a multi-criteria method for the life-cycle assessment of road projects in Poland (RID II, 2025). The method encompasses two key stages of investment planning. The first involves selecting the optimal location for the proposed investment, while the second focuses on determining functional-technical and material-technological solutions for the chosen route. This paper concentrates on the first stage. The multi-criteria analysis incorporated four main categories of evaluation criteria: functional-technical, economic, environmental, and social. Special emphasis was placed on social criteria, which, despite being the most contentious, are crucial for assessing the sustainability of infrastructure development.

The current Polish legal framework incorporates both environmental and social criteria within the environmental impact assessment (EIA) process. In this context, "environmental impact" is broadly defined to include effects on human health (Directive, 2011; Act, 2008). The EIA report is required to identify the option considered most environmentally favourable. Importantly, the legally defined environmental criteria also encompass selected social aspects, with particular attention given to the potential for social conflict or protest. Moreover, the obligation to conduct public consultations during both the preparation of the EIA report and the overall assessment process further underlines the significance of social considerations within the existing regulatory system.

Environmental impact assessments analyse projects in terms of their technical aspects, environmental impact, costs and social considerations. The goal is to deliver a holistic sustainability analysis, aligned with the life cycle sustainability assessment (LCSA) framework (UNEP, 2020). Within this context, social criteria are a vital component of sustainability-oriented assessments. It is essential to consider not only direct impacts on individuals and local communities but also indirect effects. Tangible impacts such as land occupation, demolition, noise exposure, improved connectivity, or the end of transport exclusion are relatively easy to identify and are typically included in assessments.

However, more complex issues often arise, particularly those involving intangible values, such as diminished access to environmental amenities or cultural landscapes, and lost benefits, including reduced access to ecosystem services. These aspects are frequently underrepresented or inadequately assessed.

Despite the identification of environmental impacts and the availability of clearly superior options in environmental terms, infrastructure projects are often delayed. This has been repeatedly observed in environmental impact assessment practice. Public opposition, particularly from communities directly affected by proposed road investments, is a common factor. Such protests often reflect not a disregard for social criteria, but rather insufficient or inappropriate methodologies for identifying and evaluating them. Existing analytical approaches are frequently biased, superficial, or overly simplified, failing to capture the complexity and interplay of social factors that influence decision-making.

In response, this article presents a revised approach to selecting and classifying environmental and social criteria for evaluating road investment alternatives. The authors first draw on a review of international literature and practices, along with challenges specific to Polish social policy, to develop a catalogue of social criteria suitable for structured public consultations conducted through survey research. These consultations are directed at residents of areas directly affected by the investment. To validate and refine the proposed criteria, surveys were carried out among both individual and institutional stakeholders.

Second, the authors suggest reclassifying selected environmental criteria, such as those related to noise, protected areas, archaeological sites, and historical buildings, as social criteria. While these aspects are traditionally linked to environmental and spatial contexts, they also have a direct impact on quality of life, living conditions, and cultural identity. Their reclassification facilitates a deeper

DOI: 10.34659/eis.2025.93.2.1237

understanding of their importance from the perspective of public perception and societal self-awareness within the broader ecosystem.

Accordingly, the paper recommends a clear conceptual and methodological separation between environmental and social criteria in multi-criteria analyses. This distinction enhances the analytical precision and relevance of such assessments by acknowledging the differing cognitive and decision-support functions of each category.

Social impacts of infrastructure investment – a literature review

Investments in roads have a significant social impact, particularly in rural areas and in developing countries, where they improve accessibility and mobility and meet the socio-economic needs of residents. They also promote safety and alleviate poverty (Bhusal et al., 2023; Manggat et al., 2018). Positive social impacts of road investments include improved quality of life, enhanced social integration, reduced commuting times, and better access to markets, services, and infrastructure. These improvements often translate into lower emissions and broader societal benefits (Tini et al., 2018). In rural areas, enhanced road accessibility influences multiple sectors such as education, employment, healthcare, agriculture, marketing, and tourism, while also reshaping daily life in local communities. However, the adverse effects of road development must also be acknowledged. These include a rise in traffic accidents, increased exposure to air and noise pollution, and, in some contexts, violations of human rights (Adewumi, 2022; Treviño-Lozano, 2022). In developing countries, such challenges are intensified by inadequate infrastructure, limited human resources, and financial constraints. Moreover, public policies often fail to address local needs effectively (Manggat et al., 2018), and critical issues related to safety and risk management are sometimes overlooked (Adewumi, 2022).

Distributional effects are another key concern. Road tolls, for example, disproportionately burden low-income populations by restricting their mobility and access to opportunities (Hosford et al., 2021). On the other hand, toll implementation can contribute to improved air quality and associated health benefits (Ghassabian et al., 2024). In high-income countries, investments in road infrastructure are generally associated with a reduction in fatal accidents, although the magnitude of this effect varies with GDP levels (Navarro-Moreno et al., 2023).

Various methodological approaches are employed to analyse infrastructure investments and to identify and measure their social impacts. The most common approaches are Social Impact Assessment (SIA), Social Cost-Benefit Analysis (SCBA), Wider Economic Benefits (WEB) and Social Life Cycle Assessment (S-LCA).

SIA is an integrated process combining research, planning, and management aimed at identifying and forecasting the impact of infrastructure projects on social life, health, culture, and political and economic systems. According to the International Association for Impact Assessment IAIA (2024), this approach includes stakeholder identification and engagement, baseline data collection, impact forecasting, development of mitigation measures, and impact monitoring. As Vanclay (2003) notes, social effects encompass changes in lifestyle, culture, social structure, political institutions, and public health.

In the literature, SIA is presented as both an analytical and participatory tool. For instance, stakeholder interviews were used to assess changes in quality of life and transport accessibility resulting from a local road investment in Wales (Lucas et al., 2022). Similarly, survey-based approaches allow researchers to analyse residents' priorities and perceived impacts of traffic on their daily lives (Anciaes et al., 2017).

SCBA represents a key quantitative tool, enabling the valuation of the social costs and benefits of infrastructure investments (De Wit & Over, 2024). This includes evaluating service availability, safety, health outcomes, environmental effects, and business productivity. In Poland, SCBA was applied in the evaluation of investment variants for the AmberExpo project (Zamojska & Próchniak, 2017). A significant component of SCBA is the estimation of road accident costs, which internationally range from 1.1% to 2.9% of GDP (Wijnen & Stipdonk, 2016). Increasingly, more sophisticated economic models are being used in this context, incorporating variables such as unemployment, alcohol consumption, and weather conditions (Navarro-Moreno et al., 2023).

DOI: 10.34659/eis.2025.93.2.1237

In contrast, S-LCA, as proposed by UNEP (2020), enables the evaluation of social impacts throughout the life cycle of a product or service, including road infrastructure, from the initial planning stage through to operation and decommissioning. The literature emphasises the need to integrate this approach with other environmental and socio-economic assessment tools. It also highlights the importance of considering post-average social impacts and the opportunity cost of resource use (De Rus et al., 2022). In this context, social value may be expressed through macro-level willingness-to-pay to achieve specific net benefits.

International organisations such as the World Bank and the UN Environment Programme (UNEP) stress the importance of involving local communities in the planning process and implementing mechanisms to mitigate negative impacts (Kahangirwe & Vanclay, 2024; Treviño-Lozano, 2022). Recommended measures include compensation, environmental mitigation strategies, resettlement plans, and fair compensation mechanisms.

The Australian model promotes separate recognition of wider economic benefits (WEBs), which, although accounted for independently, play an integral role in decision-making (Australian Government, 2021). The UK, by comparison, applies a more integrated system based on the Transport Analysis Guidance (Department for Transport, 2018). This framework includes economic factors (such as WEBs), environmental elements (e.g. land use, urban environment, and heritage), and social aspects (such as accessibility, safety, and benefit distribution) (IDCJ, 2003). It also incorporates distributional analysis to examine how various social groups are affected.

Contemporary evaluation frameworks increasingly incorporate methods for monetising social value. A widely adopted approach is the four-step analysis proposed by Boardman et al. (2017), which includes (1) cataloguing impacts, (2) quantitatively predicting those impacts, (3) calculating both financial and non-financial outcomes, and (4) determining the project's net value, including sensitivity analysis.

Despite methodological differences, all of the approaches reviewed share a common objective: to account for the complex and often intangible social dimensions of investment projects. As emphasised by Gouett et al. (2020), Blanquart et al. (2020) and Kyriacou et al. (2019) such evaluations must be holistic, recognising not only direct outcomes but also the broader influence of public authorities in shaping long-term project impacts.

Environmental and social criteria used to select a road investment option in Poland

The authors began by analysing the existing legal and procedural framework governing the selection of road investment options in Poland. This analysis included a review of relevant EU directives (Directive, 2000; Directive, 2002; Directive, 2009; Directive, 2011), as well as national legislation, such as the Environmental Protection Law Act (Act, 2008). Additionally, technical guidelines, manuals, and instructions issued by the General Directorate for National Roads and Motorways (GDDKiA), including the Manual for the Preparation of Environmental Impact Assessments (GDDKiA, 2008), were considered.

The authors also examined the applied practices of multi-criteria analysis (MCA) in infrastructure planning, based on several dozen empirical documents. These included Environmental Impact Reports, Project Information Sheets, and Multi-Criteria Comparative Analyses related to completed road investments. The GDDKiA provided access to these materials.

Building on this comprehensive review, the authors compiled a catalogue of environmental and social criteria currently used to evaluate road investment options in Poland. This catalogue, presented in Table 1, served as a reference point for developing the authors' own classification and definitions of social and environmental factors and proposing revised methods of measuring their impacts. The catalogue's criteria are predominantly quantitative and play a crucial role in shaping the decision-making process.

DOI: 10.34659/eis.2025.93.2.1237

Table 1. Identified Environmental and Social Factors

Criteria Subgroup	Criterion	Measures (parameters, indicators) for analysis and evaluation
ŚRO1. Natura 2000 sites	ŚRO1.1. Collisions with Natura 2000 sites	length or surface of the collision
	ŚRO1.2. Distance to Natura 2000 site boundaries	smallest distance in a straight line
	ŚRO1.3. Conflicts with priority habitats within Natura 2000 sites	collision surface
ŚRO2. Protected areas outside Natura 2000 sites	ŚRO2.1. Collisions with priority habitats of Natura 2000 sites	collision surface
	ŚRO2.2. Collisions with legally protected areas (national parks, nature reserves, landscape parks, etc.).	collision surface
	ŚRO 2.3. Collisions with spas	collision surface
ŚRO3. Forests, woodland, shrubland	ŚRO3.1. Area of forest, woodland or bushland cleared	collision surface
	ŚRO 3.2. Number of trees to be felled	number of trees
ŚRO4. Protected plants, fungi and lichens	ŚRO4.1. Collisions with vascular plant sites	area or number of collisions
	ŚRO4.2. Collisions with moss and lichen sites	area or number of collisions
	ŚRO4.3. Collisions with fungi sites	area or number of collisions
ŚRO5. Protected animal species	ŚRO5.1. Collisions with invertebrate sites	area or number of collisions
	ŚRO5.2. Collisions with ichthyofauna sites	area or number of collisions
	ŚRO5.3. Collisions with herpetofauna sites	area or number of collisions
	ŚRO5.4. Collisions with bird sites	area or number of collisions
	ŚRO5.5. Collisions with mammalian sites (except bats)	area or number of collisions
	ŚRO5.6. Collisions with bat habitats	area or number of collisions
ŚRO6. Ecological corridors	ŚRO6.1. Length of collisions with ecological corridors	length of intersection of main and local migration corridors
ŚRO7. Surface waters	ŚRO7.1. Collision with the protective zone of a surface water intake	intersection length
	ŚRO7.29. Collision with watercourses or bodies of water	intersection length
	ŚRO7.3. Occupied wetland area according to RAMSAR	collision area
	ŚRO7.4. Collisions with bathing sites	collision area
ŚRO8. Groundwater	ŚRO8.1. Collision with protection zones of underground water intakes	intersection length
	ŚRO8.2. Length of mileage over vulnerable groundwater areas	intersection length
	ŚRO8.3. Length of route over groundwater reservoirs	intersection length
ŚRO9. Soils	ŚRO9.1. Occupied protected land area	collision area
ŚRO10. Natural resources	ŚRO10.1. Collisions with mining grounds	collision area
	ŚRO10.2. Collisions with mining areas	collision area
	ŚRO10.3. Collisions with raw material deposits	collision area
ŚRO11. Waste	ŚRO11.1. Amount of waste produced	quantity generated in the implementation, operation and decommissioning phases
ŚRO12. Noise	ŚRO12.1. Population exposed to above-normal noise	number of people
ŚRO13. Air	ŚRO13.1. NOx emissions	volume of emissions
ŚRO14. Climate	ŚRO14.1. CO2 emissions	numerical indicator calculated for the assumed time horizon
ŚRO15. Monuments	ŚRO15.1. Collisions with architectural monuments	number of collisions
	ŚRO15.2. Collisions with architectural monuments	number of collisions

DOI: 10.34659/eis.2025.93.2.1237

The assessment framework includes both environmental and social criteria. The choice of evaluation method and criteria selection is typically left to the discretion of the analyst responsible for the study. A review of approximately 100 investment documents indicates that environmental criteria are consistently prioritised and well-documented. The selection process for the preferred variant typically involves conducting environmental inventories and applying modelling tools to simulate the dispersion of air pollutants and road noise.

In contrast, social criteria are generally limited to an objective indicator (the number of residential demolitions) and a subjective indicator (the occurrence of social conflict). The primary method of assessing social impacts is through public consultation; however, these consultations are seldom structured or standardised. The selection of social criteria and the assignment of weights, where applicable, were mainly arbitrary, with quantitative assessments rarely performed. Consultations were typically limited to public meetings preceded by the publication of relevant documentation. As a result, these meetings were largely attended by individuals opposed to the proposed investment. Consequently, the broader social costs and benefits of alternative options remain largely unidentified and unquantified, limiting the effectiveness of the decision-making process.

Proposal for New Social Criteria

Based on a comprehensive literature review and empirical research, the authors developed a catalogue of social criteria for assessing the social impact of road investments in Poland. The sources informing this catalogue included:

- A review of practices in both European and non-European countries, notably the UK, Germany, and China, as well as World Bank guidelines and numerous publications on methods for estimating social costs;
- An analysis of key problem areas in national and regional social policies in Poland;
- The authors' empirical research conducted among individual and institutional stakeholders;
- A review of current practices in multi-criteria analysis (MCA) of road investments in Poland, including Project Information Sheets made available by the General Directorate for National Roads and Motorways (GDDKiA).

While international practices were considered in compiling the catalogue of social criteria, no single universally accepted approach was identified. Although some countries employ advanced methods for estimating social costs and conducting public consultations, practices vary significantly due to differences in legal frameworks, local conditions, and methodological traditions.

In light of this diversity and the need to adapt the evaluation framework to the Polish context, the authors conducted original empirical research using the CATI (Computer-Assisted Telephone Interviewing) method. A total of 1,238 interviews were carried out with randomly selected individual residents, and 105 with representatives of institutional stakeholders across six locations affected by road investment projects implemented by the General Directorate for National Roads and Motorways (GDDKiA). The CATI method ensured consistency in data collection and enabled a systematic assessment of respondents' perceptions of social impacts. During the interviews, participants evaluated selected social effects using a scale ranging from –5 (maximum negative impact) to +5 (maximum positive impact).

The assessment focused on three main domains:

(1) Economic activity, including factors such as business location attractiveness, competitiveness, access to markets and labour, entrepreneurship development, and the economic activation of socially excluded groups;
(2) Transport behaviours, encompassing journey frequency and length, perceived travel quality, and car usage patterns;
(3) Local area impacts, covering issues such as functional connectivity or fragmentation, perceived accident rates, traffic volume, population mobility, quality of life, job availability, and access to cultural, educational, and healthcare services, as well as effects on the landscape and cultural heritage (Bąk et al., 2024).

Table 2 presents the resulting catalogue of social impacts recommended for consideration in assessing road investment options. A total of 18 indicators were proposed and organised into two

DOI: 10.34659/eis.2025.93.2.1237

sub-criterion categories. Social impacts were assessed using quantitative and qualitative approaches; however, no monetary valuation was assigned to these effects.

The first sub-criterion, "Quality of life of local communities," comprises quantitative indicators and questionnaire survey responses. Eleven indicators were identified within this category. The second sub-criterion, "Economic activity," relies exclusively on data from the stakeholder surveys to evaluate impacts across seven key areas.

Table 2. Classification of Social Impacts

Criteria subcategory	Criterion	Measures (parameters, indicators) for analysis and evaluation
SPO1. Quality of life of local communities	SPO1.1. Safety of road users	residents' and institutions' perception of the level of security in the area affected by the investment
	SPO1.2. Travelling time	residents' and institutions' perception of the impact of investments on travel time
	SPO1.3. Quality of travel	residents' and institutions' perception of the impact of investments on the quality of travel
	SPO1.4. Accessibility to cultural services and goods	residents' and institutions' perceptions of the impact of investments on accessibility to cultural services and goods
	SPO1.5. Accessibility to education	residents' and institutions' perceptions of the impact of investments on access to education
	SPO1.6 Accessibility to healthcare services	residents' and institutions' perceptions of the impact of investments on access to health services
	SPO1.7. Accessibility to jobs	residents' and institutions' perceptions of the impact of investments on accessibility to jobs
	SPO1.8. Level of transport exclusion	residents' and institutions' perception of the impact of investments on changing the level of transport exclusion
	SPO1.9. Demolition / dismantling of buildings	number of buildings to be demolished
	SPO1.10. Local development plans	number of conflicts with land-use facilities and perception by residents and institutions of the impact of investments on the connection / separation of functional areas
	SPO1.11. Difficulties of life during road construction	hardships in the form of detours during construction
SPO2 Economic activity	SPO2.1. Location of economic activity	residents' and institutions' perceptions of the impact of investment on business location
	SPO2.2. Competitiveness of companies located in the region	perception by residents and institutions of the impact of investments on the competitiveness of enterprises located in the region
	SPO2.3. Market attractiveness	residents' and institutions' perception of the impact of investments on the attractiveness of the local market
	SPO2.4. Availability of raw materials	residents' and institutions' perception of the impact of investments on the availability of raw materials
	SPO2.5. Availability of markets	residents' and institutions' perception of the impact of investments on the availability of markets
	SPO2.6. Development of entrepreneurship	citizens' and institutions' perception of the impact of investment on entrepreneurship development
	SPO2.7. Number of jobs	residents' and institutions' perception of the impact of investments on the number of jobs

During the project, all environmental and social criteria underwent in-depth analysis, leading to the development of final sets that differ substantially from the original ones. Notably, several criteria initially classified as environmental have been reclassified under the social criteria category (see Table 3).

Table 3. Environmental Criteria Transferred to Social Criteria

Criteria subcategory	Criterion	Measures (parameters, indicators) of analysis and evaluation
SPO3 Quality of the Natural and Social Environment	SOP3.1. Occupied protected land area	collision area
	SOP3.2. Collisions with bathing sites	collision area
	SOP3.3. Number of residential buildings with deterioration of acoustic conditions	number of buildings
	SOP3.4. Volume of NOx emissions	emissions
	SOP3.5. Collisions with archaeological sites	number of collisions
	SOP3.6. Collisions with historical monuments	number of collisions
	SOP3.7. Collisions with mineral deposits	collision area

Approach to standardisation and aggregation of criteria values

Multi-criteria decision support methods have been used for many years in the field of transport to solve complex decision-making problems. These include assessing transport systems' quality and safety level, selecting a development scenario for public transport systems, and selecting an investment location (Broniewicz & Ogrodnik, 2020, 2021). Based on a literature review, the most popular MCDM/MCDA methods applied to transport-related issues are: AHP and TOPSIS, as well as their fuzzy set-based modifications (FAHP and FTOPSIS). In addition, methods from the European decision support stream, such as PROMETHEE, ELECTRE and DEMATEL, are at the forefront. As MCDM/MCDA methods evolve, new proposals such as MARCOS, PIPRECIA and CoCoSo are constantly emerging. Figure 1 provides an overview of the most popular multi-criteria decision support methods in the transport field (methods featured in at least two studies are included). This overview is based on 243 research papers from 2000 to 2024 that are indexed in the WoS and Scopus databases (Broniewicz & Ogrodnik, 2020, 2021, 2025).

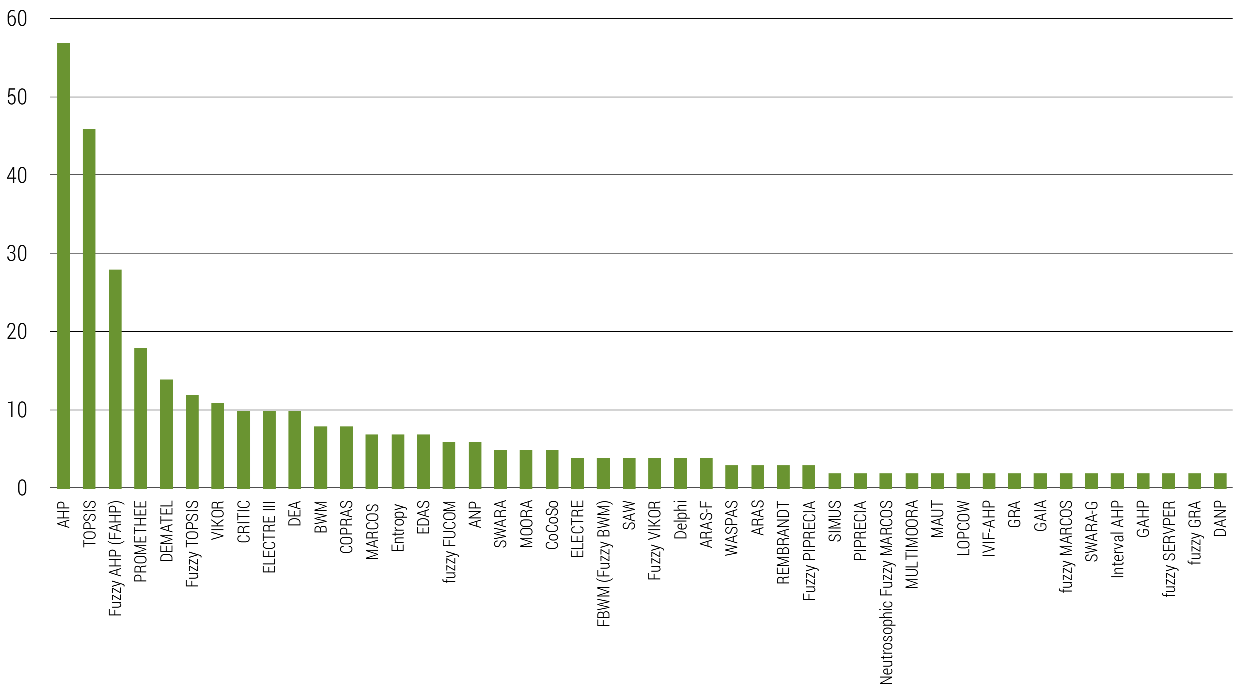

Figure 1. An overview of the most popular multi-criteria decision support methods used in the transport sector
Source: Broniewicz and Ogrodnik (2020, 2021, 2025).

DOI: 10.34659/eis.2025.93.2.1237

Based on the literature, the most popular methods include:

- the **SAW** method (short for **S**imple **A**dditive **W**eighting), also known as **the weighted sum**,
- the **TOPSIS** method (short for **T**echnique for **O**rder **P**reference by **S**imilarity to **I**deal **S**olution),
- the **AHP** method (short for **A**nalytic **H**ierarchy **P**rocess),
- the **PROMETHEE** method (short for **P**reference **R**anking **O**rganisation **METH**od for **E**nrichment **E**valuations).

The SAW method is the simplest method for aggregating the values of criteria with different weights, which are expressed by an appropriate set of weights. The TOPSIS method is a popular approach to multi-criteria analysis, as demonstrated by its wide range of applications in solving various multi-criteria decision-making problems (Behzadian et al., 2012). The AHP method is as popular as the TOPSIS method, as evidenced by the numerous theoretical and practical studies on it (Sipahi & Timor, 2010). The PROMETHEE method is also very popular (Behzadian et al., 2010) and is supported by free dedicated software (Promethee Method, 2024).

Based on the authors' experience and expertise, this study proposes using the relatively simple SAW method to aggregate the appraisals of the alternatives. This method is no less effective than the others. In the SAW method, the aggregated assessments of individual options are determined using a weighted sum formula, i.e. the sum of the products of the standardised option assessments (in light of the adopted criteria) and the criteria weights:

$$Z_i = \sum_{j=1}^{n} z_{ij} w_j, \tag{1}$$

where:
z_{ij} – standardised evaluation of the i variant in the light of the j criterion,
w_j – weight of the j criterion.

With this approach, ranking the variants in order, from the most to the least favourable, is determined based on the decreasing value of the aggregated assessments resulting from formula (1).

A multi-criteria comparative analysis using a set of social and environmental criteria requires aggregating the evaluated road investment alternatives. Due to the heterogeneity of the individual factors and their respective measures, it is necessary to bring them into uniform form. This process is referred to as normalisation or standardisation. Selecting an appropriate standardisation/normalisation method for the assessments is crucial. For example, standardisation can be performed using the following formula:

$$z_{i,k} = \frac{x_{i,k} - \bar{x}_k}{s_k}, \tag{2}$$

whereby:
s_k – the standard deviation of the k characteristic, which is calculated as

$$s_k = \sqrt{\frac{\sum_{i=1}^{n} \left(x_{i,k} - \bar{x}_k\right)^2}{n-1}}, \tag{3}$$

where:
$\bar{x}_k$ – the arithmetic mean of the k-trait.

If both stimulant and destimulant factors are present among the evaluation criteria, the destimulants must first be converted to stimulants based on the following formula:

$$x_{i,k} = \frac{d_{i,k}}{min\{d_{i,k}\}}, \quad \text{or} \quad x_{i,k} = 1 - \frac{d_{i,k}}{max\{d_{i,k}\}}, \tag{4}$$

where:
i – investment variant number,
k – number of features,
$d_{i,k}$ – value of k feature for i variant,
$min\{d_{i,k}\}$ – minimum value of k feature,
$max\{d_{i,k}\}$ –maximum value of k feature.

DOI: 10.34659/eis.2025.93.2.1237

However, standardisation is problematic in the case of road investment projects due to the relatively small number of options to be compared. Therefore, the potential usefulness of different standardisation methods must be evaluated. Two of the most popular standardisation methods are outlined below.

The first is linear scaling according to the following formula:

- for stimulants

$$z_{i,k} = \frac{x_{i,k} - min\{x_{i,k}\}}{max\{x_{i,k}\} - min\{x_{i,k}\}}, \tag{5}$$

- for destimulants

$$z_{i,k} = \frac{max\{x_{i,k}\} - x_{i,k}}{max\{x_{i,k}\} - min\{x_{i,k}\}}, \tag{6}$$

where:
$min\{x_{i,k}\}$ – minimum value of k feature,
$max\{x_{i,k}\}$ – maximum value of k feature.

It should be noted that standardisation based on the two formulas above always yields extreme evaluations of 0 and 1, which distorts the proximity of post-standardisation evaluations to pre-standardisation option evaluations.

In addition to standardisation based on formulae (5) or (6), other methods of linear standardisation have also been considered. One of these is standardisation according to the following formula:

- for stimulants:

$$z_i = \frac{x_{i,k}}{x_{max}}, \tag{7}$$

- for destimulants:

$$z_i = \frac{x_{min}}{x_{k,i}}, \tag{8}$$

Unlike standardisation according to formulas (5) and (6), standardisation using formulas (7) and (8) ensures that the standardised assessments remain proportional to the original assessments before standardisation. This makes it seem more appropriate, especially in the case of slight differences between the values of assessments of individual variants. However, it should be noted that standardisation using formulas (5) and (6) or (7) and (8) works without issue when the ratings of the variants are positive. This situation occurs most frequently in the practice of multi-criteria decision support.

It is not possible to rule out the possibility that the values of the criteria will have different signs. They may even be negative. This means the criteria values for one or more variants may equal 0. Such a situation applies to almost all social factors. The only exceptions are K.1, K1.10, and K1.11, for which the ratings of the variants, in light of the individual measures, would be obtained using a questionnaire survey. These ratings would range from -5 (lowest rating) to +5 (highest rating), in steps of 1. In this case, standardisation using formulae (7) or (8) would be problematic.

Therefore, to maintain a consistent approach to standardisation for all the factors identified in the social and environmental groups, formulas (5) and (6) are recommended.

DOI: 10.34659/eis.2025.93.2.1237

Consequences of Assigning Factors to a Specific Category of Multi-Criteria Analysis

The synthetic ratings of the options are determined by aggregating the criteria values using formula (8), which involves criteria weights. Although the weighting process is inherently subjective, it is possible to identify criteria that are more important than others based on past practice. For this article, therefore, the weights of the criteria included in the original environmental and social sets were determined. To this end, the results of questionnaires regarding the importance of the criteria were used. These questionnaires were completed by specialists in road investment design and by specialists experienced in dealing with environmental and social issues. Based on these surveys, scores expressing the importance of each criterion (P_k) were determined on a scale from 5 to 100 in steps of 5. Then, based on these scores, the criterion weights (w_k) were assigned to each group for the original and final sets of criteria. The values of the criterion weights were determined using the following formula:

$$w_k = \frac{P_k}{\sum_{k=1}^{n} P_k}. \tag{9}$$

which ensures that the sum of the weights within a given group of criteria adds up to unity.

Table 4 compares the values of the weights of the criteria obtained in both versions of the criterion sets. The green colour indicates criteria that have been shifted from environmental to social criteria, and the red colour indicates criteria that have been removed from the original sets.

Table 4. Weights of Individual Criteria in the environmental and social criteria sets in the Original and Final Approaches

Symbol and name of the criterion	Score (number of points)	Weights in the primary set	Weights in the final set	Changes in weight values
ŚR01.1. Collisions with Natura 2000 sites	100	0.060	0.083	0.022
ŚR01.2. Distance to Natura 2000 site boundaries	100	0.060	0.083	0.022
ŚR01.3. Collisions with priority habitats within Natura 2000 sites	80	0.048	0.066	0.018
ŚR02.1. Collisions with priority habitats of Natura 2000 sites	35	0.021	0.029	0.008
ŚR02.2. Collisions with legally protected areas (national parks, nature reserves, landscape parks, etc.)	40	0.024	0.033	0.009
ŚR02.3. Collisions with spas	10	0.006	0.008	0.002
ŚR03.1. Area of cleared forest, woodland or shrubland	25	0.015	0.021	0.006
ŚR03.2. Number of trees to be felled	25	0.015	0.000	-
ŚR04.1. Collisions with vascular plant sites	25	0.015	0.021	0.006
ŚR04.2. Collisions with moss and lichen sites	25	0.015	0.021	0.006
ŚR04.3. Collisions with fungi sites	20	0.012	0.017	0.004
ŚR05.1. with invertebrate sites	70	0.042	0.058	0.016
ŚR05.2. Collisions with ichthyofauna sites	70	0.042	0.058	0.016
ŚR05.3. Collisions with herpetofauna sites	70	0.042	0.058	0.016
ŚR05.4. Collisions with bird sites	80	0.048	0.066	0.018
ŚR05.5. Collision with mammal sites (except bats)	80	0.048	0.066	0.018
ŚR05.6. Collisions with bat habitats	70	0.042	0.058	0.016
ŚR06.1. Length of collisions with ecological corridors	40	0.024	0.033	0.009
ŚR07.1. Collision with the protective zone of a surface water intake	40	0.024	0.033	0.009

DOI: 10.34659/eis.2025.93.2.1237

Symbol and name of the criterion	Score (number of points)	Weights in the primary set	Weights in the final set	Changes in weight values
ŚRO7.29. Collision with watercourses or bodies of water	20	0.012	-	-
ŚRO7.3. Occupied wetland area according to RAMSAR	80	0.048	0.066	0.018
ŚRO7.4./ SPO3.2. Collisions with bathing sites	25	0.015	0.022	0.007
ŚRO8.1. Collision with protection zone of underground water intake	40	0.024	0.033	0.009
ŚRO8.2. Length of route over vulnerable groundwater areas	40	0.024	0.033	0.009
ŚRO8.3. Length of route over groundwater reservoir	40	0.024	0.033	0.009
ŚRO9.1./ SPO3.1. Area of occupied of protected land area	100	0.060	0.088	0.028
ŚRO10.1. Collisions with mining grounds	25	0.015	-	-
ŚRO10.2. Collisions with mining areas	25	0.015	-	-
ŚRO10.3./ SPO3.7. Collisions with raw material deposits	25	0.015	0.022	0.007
ŚRO11.1. Amount of waste produced	5	0.003	0.004	0.001
ŚRO12.1./ SPO3.3. Population exposed to above-standard noise / Number of buildings where acoustic conditions deteriorated	100	0.060	0.088	0.028
ŚRO13.1./ SPO3.4. Emissions of pollutants expressed as NOx	25	0.015	0.022	0.007
ŚRO14.1. CO2 emissions	25	0.015	0.021	0.006
ŚRO15.1./ SPO3.5. Collisions with archaeological sites	40	0.024	0.035	0.011
ŚRO15.2./ SPO3.6. Collisions with monuments	40	0.024	0.035	0.011
SPO1.1. Safety of road users	100	0.122	0.092	-0.030
SPO1.2. Travelling time	90	0.110	0.083	-0.027
SPO1.3. Quality of travel	90	0.110	0.083	-0.027
SPO1.4. Accessibility to cultural services and goods	35	0.043	0.032	-0.010
SPO1.5. Accessibility to education	35	0.043	0.032	-0.010
SPO1.6. Accessibility to healthcare services	35	0.043	0.032	-0.010
SPO1.7. Accessibility to jobs	40	0.049	0.037	-0.012
SPO1.8. Level of transport exclusion	40	0.049	0.037	-0.012
SPO1.9. Demolition / dismantling of buildings	100	0.122	0.092	-0.030
SPO1.10. Local zoning plans	30	0.037	-	-
SPO1.11. Hardships in life during road construction	20	0.024	-	-
SPO2.1. Location of economic activity	30	0.037	0.028	-0.009
SPO2.2. Competitiveness of companies located in the region	30	0.037	0.028	-0.009
SPO2.3. Market attractiveness	30	0.037	0.028	-0.009
SPO2.4. Availability of raw materials	25	0.030	0.023	-0.007
SPO2.5. Availability of markets	30	0.037	0.028	-0.009
SPO2.6. Development of entrepreneurship	30	0.037	0.028	-0.009
SPO2.7. Number of jobs	30	0.037	0.028	-0.009

Unlike standardisation according to formulas (5) and (6), standardisation using formulas (7) and (8) ensures that the standardised assessments remain proportional to the original assessments before standardisation.

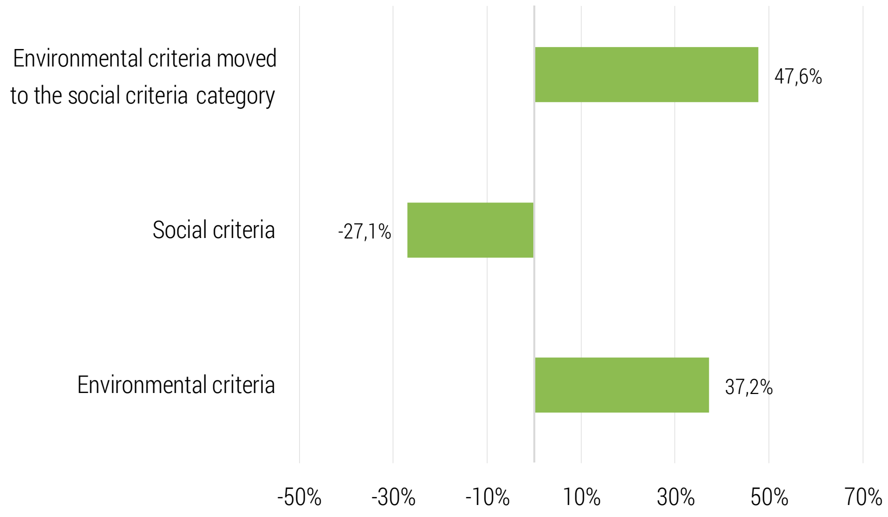

Figure 2. Percentage change in criteria weights

Conclusions

The preparation of a specific road investment project is a very complex process that requires a number of in-depth analyses involving specialists from various fields. Multi-criteria analysis plays a very important role, as its aim is to select the most appropriate location for the investment. There is no doubt that the result of a multi-criteria analysis is, by definition, the sum of its various components, e.g. a set of acceptable investment options, a set of comparison criteria and a set of weights that determine their mutual validity.

In the past, environmental and social criteria have generally been decisive in selecting the unfavourable option, which is invariably accompanied by the differing preferences of different stakeholders. This trend is likely to continue. In the course of developing a multi-criteria lifecycle assessment method for road projects (RID II), the authors therefore paid great attention to identifying and segmenting environmental and social criteria for future road investment analyses.

As described in the following sections of this paper, the results of this study have shown that identification and segmentation play a primary role in laying the foundations for multi-criteria analysis. Assigning criteria to one of the aforementioned groups can significantly impact the values of the criteria weights, particularly when accompanied by relatively high weighting values assigned to certain criteria compared to others.

The example presented in the paper shows that shifting criteria with relatively high weights from the environmental set to the social set resulted in a significant increase in the weights of the shifted criteria. This increase was directly related to the shift from a relatively large set of environmental criteria to a smaller set of social criteria.

Assigning the same importance to the set of environmental criteria as to the set of social criteria results in an increase in the value of the individual environmental criteria weights. The opposite effect occurs with the social criteria, since an increase in their number translates directly into a corresponding decrease in the weights of the individual criteria (from the original set). A detailed assessment is only possible on the example of a specific investment. This is because it is necessary to know how the adopted way of segmenting environmental and social criteria may affect the outcome of the multi-criteria analysis. The same is true of the weights of the criteria and their changes. As with the considerations set out in this article, however, such an assessment would not provide a basis for drawing conclusions that could be applied to all investments and related multi-criteria analyses.

Acknowledgements

The research was carried out as part of the INROAD-WAP project: A model method for evaluating road investments at the STEŚ stage, taking into account the principles of sustainable development throughout the road's life cycle. The project is a Joint Undertaking entitled "Development of Road Innovations" (RID-II/0019/2022), funded by the National Centre for Research and Development (NCBR) and the General Directorate for National Roads and Motorways (GDDKiA).

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Conceptualisation, M.B., M.Bu., K.G., P.B., D.T., E.B., A.K. and T.S.; literature review, K.G., K.J., M.B., P.B. and D.T.; methodology, A.D., M.B., K.G., P.B. and D.T.; formal analysis, E.O., E.B., A.K. and K.O.; writing, K.G., M.B., A.K., E.B. and K.O.; conclusions and discussion, A.K.

The authors have read and agreed to the published version of the manuscript.

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IDENTYFIKACJA I SEGMENTACJA KRYTERIÓW SPOŁECZNYCH I ŚRODOWISKOWYCH W RAMACH ANALIZY WIELOKRYTERIALNEJ WYBORU WARIANTÓW INWESTYCJI INFRASTRUKTURALNYCH W TRANSPORCIE DROGOWYM

STRESZCZENIE: Badania przeprowadzone w różnych krajach wskazują, że inwestycje drogowe mają zarówno pozytywne, jak i negatywne skutki społeczno-ekonomiczne oraz środowiskowe. Celem artykułu jest analiza wyzwań związanych z klasyfikacją czynników społecznych i środowiskowych w kontekście analiz wielokryterialnych dotyczących inwestycji drogowych. W badaniu na podstawie przeglądu literatury i badań własnych zaproponowano nowe zestawy kryteriów społecznych i środowiskowych, które znacząco różnią się od pierwotnych, oraz wykazano potrzebę zmiany klasyfikacji niektórych kryteriów. Przeprowadzona analiza dowodzi, że sposób klasyfikacji wpływa na ocenę i wybór wariantów inwestycyjnych. Wartość dodana pracy polega na przedstawieniu zmodyfikowanego podejścia do oceny społeczno-środowiskowej, które może znaleźć zastosowanie w praktyce planowania infrastruktury transportowej.

SŁOWA KLUCZOWE: transport drogowy, inwestycje infrastrukturalne, analiza wielokryterialna, wpływ społeczny, wpływ środowiskowy