Journal of Transportation and Logistics
JTL 2024, 9 (2), 245–259
DOI: 10.26650/JTL.2024.1437521

RESEARCH ARTICLE

Evaluation of Sustainable Transportation in 25 European Countries Using GRA and Entropy MABAC

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ABSTRACT
The increasing demand for sustainable transportation systems has driven researchers and policymakers to investigate new methodologies. European countries, with their diverse landscapes and varying population densities, have been particularly focused on optimizing transportation systems under the aim of achieving sustainability goals. This study evaluates the sustainable transportation practices in 25 European Union member countries through the implementation of grey relational analysis (GRA) and the entropy-multi-attributive border approximation area comparison (entropy-MABAC) methodology. The proposed study specifically examines the sustainability of the transportation system in these European countries. Twelve criteria have been established, providing a comprehensive analysis of various aspects of the sustainability of transportation systems. The utilization of GRA and entropy-MABAC methodology offers a robust framework for decision-makers to make informed choices regarding transportation policies and investments, ensuring a more sustainable and efficient future for European transportation systems. The findings rank Sweden and Germany first and second, respectively. Poland ranks last in both. The correlation analysis produced a coefficient of 0.8218, which is near 1 and implies a substantial correlation between the outcomes generated by GRA and entropy-MABAC, indicating that the outputs from both approaches are consistent. The findings indicate that the two methods are reliable and yield similar results.

Keywords: Entropy-MABAC, Grey Relational Analysis, Sustainable Transportation

1. Introduction

A nation's transportation systems profoundly affect its economic, social, and environmental dimensions. Transportation activities, though, consume a substantial amount of energy and produce a significant amount of greenhouse gas emissions, both of which makes them a great source of environmental degradation (Rogers & Weber, 2011). The relationship between sustainability and transportation is essential and intricate, deeply connected to the ecological, societal, and economic dimensions of modern society. Transportation is crucial to our daily lives, facilitating the connection of people, goods, and services. However, it also carries substantial implications for the well-being and future of our planet. The concept of sustainability in transportation pertains to the capacity to fulfill present transportation requirements while safeguarding the potential of future generations to fulfill their own needs. The concept entails the comprehensive evaluation of the environmental, social, and economic repercussions associated with transportation systems, with the aim of mitigating adverse consequences and optimizing advantageous outcomes (Illahi, U., & Mir, 2019). In the literature, there are several studies which consider sustainable transportation systems by taking into account greenhouse gas emissions (Rehman et al., 2023; Soni et al., 2022), air and water quality (Johnson & White, 2010; Lev-On et al., 2005), safety (Babaei et al., 2022), the social dimension (Karjalainen & Juhola, 2019), energy efficiency (Palander et al., 2020), and many other concerns.

There is a growing consensus among scholars and experts that a sustainable transportation system should possess certain key attributes, ensuring safety, efficiency in facilitating accessibility and mobility, and promoting economic productivity, all while minimizing harm to the environment (Amekudzi et al., 2009). The present study investigates the transportation-related parameters of European countries from a sustainability perspective via grey relational analysis (GRA) and the entropy-multi-attributive border approximation area comparison (entropy-MABAC) methodology. The GRA method was selected for its capacity to effectively manage systems that involve uncertain and imprecise information. This approach demonstrates exceptional proficiency in examining intricate systems by converting qualitative data into quantitative metrics (Hsiao et al., 2017; Liu et al., 2009). Its versatility in managing multiple datasets makes it appropriate for assessing the multidimensional character of sustainability in transportation

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Submitted: 15.02.2024 • **Revision Requested:** 26.03.2024 • **Last Revision Received:** 26.04.2023 • **Accepted:** 06.05.2024 • **Published Online:** 10.07.2024

across different European countries. In addition, the entropy-MABAC methodology provides a methodical strategy for managing difficulties related to decision-making with numerous criteria. This method ensures a fair and comprehensive evaluation of transportation systems by utilizing entropy to quantify the uncertainty and information content of specific criteria. In this way, we have considered several factors, including: freight transportation, public transportation, transportation types, energy consumption, passenger car rate, renewable sources in transportation, electric consumption in transportation, and greenhouse gas emissions (GHG). These criteria have previously been considered in the literature separately (Kraus, 2021). However, this study considers these criteria together for the first time. In addition, the reason behind selecting these criteria derives from the motivation of usage of energy source that affects GHG and effective utilization of transportation type. Limiting the study to 25 countries achieves an appropriate balance between the scope and thoroughness of the analysis. It enables a limited range of study while still offering enough data points to make significant inferences regarding sustainable transportation practices throughout Europe.

The primary objectives of this study encompass: 1) Proposing a systematic approach towards the evaluation of European countries based on their transportation sustainability profiles, 2) Applying and comparing the GRA and entropy-MABAC methodologies, 3) Evaluating the sustainability of the transportation systems in European countries by examining diverse parameters, including energy consumption and electricity consumption in transportation, renewable sources, and total GHG, 4) Providing a framework that could be utilized for a mutual consensus between European countries based on their strengths and weaknesses with respect to sustainable transportation.

1.1. Contributions of the study:

- One important aspect is the evaluation of transportation sustainability through the comparison of the GRA and entropy-MABAC techniques. This study contributes to knowledge about the applicability and efficacy of various analytical approaches in sustainable transportation assessment by demonstrating their similarities and consistent capacity to produce reliable results.
- The study offers a thorough examination of multiple factors related to sustainable transportation, such as: energy usage, usage of electricity, exploitation of renewable sources, and GHG. This comprehensive methodology allows for a comprehensive analysis of transportation sustainability, encompassing its multifaceted nature and intricacies.

This study provides useful insights for policymakers and stakeholders engaged in transportation planning and decision-making. It examines the strengths and weaknesses of several European countries in terms of transportation sustainability. Following this introductory section, Section 2 provides a literature review of transportation sustainability and multi criteria decision making (MCDM) techniques. Section 3 presents the methodology, which includes preliminaries and background information necessary to understand the proposed investigation. Section 4 outlines the approach employed for data collection and analysis, providing the results obtained from the MCDM methodologies along with a detailed discussion. Finally, Section 5 concludes the paper with a summary of key insights and avenues for future research.

2. Literature Review

The importance of developing sustainable transportation systems has grown significantly in response to the various environmental, social, and economic challenges associated with transportation modes, electricity and energy consumption, and the utilization of renewable energy sources,. The objective of this literature review is to consolidate and evaluate prior research pertaining to sustainability within the realm of transportation.

Gökçekuş et al. (2019) presented a study which aimed to incorporate the theory of MCDM into green transportation, while also promoting the use of public transportation, bicycles, and walking for travel purposes. Furthermore, this research aimed to evaluate and compare traditional sustainable transportation alternatives using a MCDM process.

Marimuthu et al. (2022) wrote an article that provides a revised method for ranking generalized interval type-2 trapezoidal fuzzy numbers. Interval type-2 fuzzy sets are beneficial for representing uncertainty and managing imprecision in decision-making data. The designed ranking method aims to tackle the difficulty of making judgments on sustainable urban transportation when various variables must be taken into account. Prioritization and ranking are important steps in providing a deep insight of the sustainable transportation and accurate decision making.

Concerning this perspective, numerous studies have been presented in the literature. One of the articles introduces a novel approach to applying the concept of shared mobility, wherein postal operators leverage their extensive networks of facilities to act as service providers (Senapati et al., 2023). In this study, the primary inquiry revolves around determining the best environmentally-friendly option that service providers should present. The study also proposes a sophisticated decision support model that utilizes Aczel-Alsina aggregation operators and power operators in the context of intuitionistic fuzzy environment to address this difficulty. The criteria weights are determined using the Shannon entropy-based power weighted technique. Another important study aims to evaluate and rank the various methods of incorporating the Metaverse into the sharing economy, considering different criteria and uncertainties (Rani et al., 2023). It presents a decision-making strategy consisting of four stages, specifically designed for the interval-valued Pythagorean fuzzy context. The first step involves proposing a new scoring function to compare interval-valued Pythagorean fuzzy numbers. Next, several interaction aggregation operations for the Individual Value Preference Function have been suggested to consolidate the knowledge of each individual in the process of group decision-making. Furthermore, a comprehensive weighing procedure is introduced to determine the objective weights of the criterion via a cross entropy-based method. It is also important to analyze the reliability of the provided ranking on sustainable transportation. Sustainable transportation concerns encompass technical elements and subjective assessments, which can be strategically reported by specialists.

In the study conducted by Santos Arteaga et al. (2023), the assessments of multiple experts are presented to illustrate the significance of strategic incentives in the rankings achieved via the implementation of MCDM methodologies. It provides a numerical demonstration of the relationship between the reporting techniques of experts and the formal instruments that decision makers have at their disposal to prevent potential manipulations of the final ranking. Technology is significant regarding sustainable transportation due to its unpredictable nature which necessitates disciplined decision making. In that aspect, Dahooie et al. (2023) conducted a study that analyzes a novel hybrid multi-criteria decision-making approach to identify internet of things (IoT) applications in the urban transportation sector for future investment. The approach utilizes a new portfolio matrix that considers two dimensions: the impact on sustainable development and the feasibility of implementing IoT. Autonomous vehicles are important factors to ensure sustainable transportation due to traffic safety, enabling efficient and effective planning, and providing a dynamic response to any change of actions. From the this point of view, Gamal et al.(2023) presents a framework for selecting autonomous vehicle selection. In this framework, type-2 neutrosophic numbers, removal effects of criteria, and combined compromise solution approaches are included, with the intent of reducing the subjectivity of human judgment.

Considering sustainable transportation, the study of Ecer et al. (2023) introduced a practical and reliable decision-making framework that can effectively address complex uncertainties in order to assess the sustainability performance of micro mobility solutions. In addition, it proposes a new methodological framework called Delphi, Logarithmic Percentage Change-Driven Objective Weighting, and Combined Compromise Solution methods with interval-valued fuzzy neutrosophic number information. This framework serves as a tool for reconciling and establishing the criteria that impact the assessment processes. Another important study was conducted by Antunes et al. (2023) and focuses on the impact of research-development and innovation on transportation sustainability performance. In this study, a novel TEA-IS model is first produced to evaluate the sustainability performance of road transportation. This hybrid DEA-TOPSIS model has the capability to examine the sustainability performance by considering the synergistic impacts among the criteria, in addition to including the advantageous aspects of each individual model. Machine learning approaches are employed to anticipate the performance levels and synergistic nature of provinces in China, based on socioeconomic and demographic factors.

Regarding the performance evaluation, the study of Zhang et al. (2023) assesses the efficiency of railway transportation in China with a systematic approach. The research first establishes the criteria for assessing the performance of railway transportation, encompassing railway safety, infrastructure, equipment, operational efficiency, and environmental sustainability. Furthermore, the weight of each index is determined by employing the intercriteria correlation approach (CRITIC), which assesses the significance of criteria importance. Furthermore, the railway transportation performance is evaluated using an MCDM approach, specifically employing the CRITIC-relative entropy method.

Systematic frameworks and assessments of strategies, systems, and alternatives are crucial to ensure efficiency and effectiveness in sustainable transportation systems. From the this point of view, Kovac et al. (2023) proposes a methodology to handle city logistics concepts. In this study, the ADAM method was applied, considering the city-dry port micro-consolidation centers. Jiang et al. (2023) conducted a study that focuses on sustainable urban road alignment planning. In order to achieve that purpose, the Delphi method and geographic information system based least-cost wide path approaches were utilized. Another study by Korucuk et al. (2023) presented a model for selecting a smart network strategy and determining the weights of criteria used in green transportation indicators. The study was conducted to build an optimal smart network strategy. The authors of the study believe that the proposed model will help businesses and governments achieve their environmental, economic, and social goals by promoting green logistics. This will involve efficiently using limited resources to ensure a sustainable environment for future generations and provide businesses with a competitive edge. In addition, the study of Bouraima et al. (2023) evaluates different railway systems for sustainable transportation, utilizing an integrated IRN SWARA and IRN CoCoSo model. The study proposed by Zagorskas and Turskis (2024) aimed to tackle the difficulty of converting car-oriented industrial parks into places that are hospitable to pedestrians and cyclists. The study aimed to estimate the potential influence on bicycle and pedestrian traffic flows by evaluating various pathway connections using a MCDM approach.

Table 1. Summary of the literature review

Authors-Year	Method	Criteria	Highlight
Gökçekuş et al., 2019	Fuzzy PROMETHEE Method	Toxics gases, climate change, noise, air quality, and capacity	Evaluating and contrasting the traditional sustainable transportation alternatives.
Marimuthu et al., 2022	Interval Type-2 Trapezoidal Fuzzy Number	Reliability, speed, capacity, cost, flexibility, energy, CO2 emissionsReliability, speed, capacity, cost, flexibility, energy, and CO2 emissions	Examines all essential aspects of transportation sustainability, encompassing the efficacy of resilient transportation systems.
Senapati et al., 2023	Intuitionistic fuzzy power Aczel-Alsina model	Cargo and space capacity, GHG emissions, investment cost, market potentialCargo and space capacity, GHG emissions, investment cost, and market potential	The topic of sustainable transportation sharing methods.
Rani et al., 2023	Interval-valued Pythagorean fuzzy model, OCRA approach	12 criteria, including: financial paradigm, Security, Critical mass of users, and the fleets in real-time	Incorporating the Metaverse into the sharing economy specifically in the transportation industry.
Santos Arteaga et al. ,2023	Hesitant fuzzy numbers, TOPSIS	24 criteria, including: Operating costs, GHG emissions, usage of fossil fuels, energy consumption, and travel costs	Converting a MCDM situation into a game-theoretic scenario within the concept of sustainable transportation.
Dahooie et al., 2023	The improved Fuzzy Cognitive Map (FCM) - Best Worth Method (BWM) method, ARAS method	Pollution, energy consumption, GHG emission/climate change, and customer accessibility to transport system	Internet of Things (IoT) in Transportation
Gamal et al., 2023	Type-2 neutrosophic numbers, compromise solution (CoCoSo) method	Price, environmentally friendly, and battery capacity of the autonomous vehicles	Choosing the most suitable autonomous vehicle.
Ecer et al., 2023	Novel IVFNN (interval-valued fuzzy neutrosophic number)-Delphi-LOPCOW (Logarithmic Percentage Change-Driven Objective Weighting)-CoCoSo framework	Land use and infrastructure, land area consumed by public transport facilities m^2, land consumption, and ecosystem degradation	Providing a framework to evaluate the sustainability of small-scale transportation methods.
Antunes et al., 2023	A novel trigonometric envelopment analysis for ideal solutions (TEA-IS)	Labor, capital, energy, GDP, GDP per capita, and population density	Evaluating the sustainability performance of road transportation.
Zhang et al., 2023	Relative entropy evaluation method, the cross-efficiency evaluation method	Railway mileage, labor, freight turnover, passenger turnover, and locomotives	Assessing the efficiency of railway transportation in China with regards to sustainability.
Kovac et al., 2023	Mathematical programming and the axial-distance-based aggregated measurement (MCDM) method	The number of cities, the number of delivery vehicle trips, delivery reliability and flexibility, and availability of traffic infrastructure	Envision an innovative proposal for a potentially sustainable city logistics concept:
Jiang et al., 2023	Systematic literature review, Delphi method, questionnaire surveys for MCDM, GIS	Traffic factors, economic factors, social factors, environmental factors, and engineering factors	Considering digitalization and parsing methodologies, factor evaluation, and road alignment creation in the context of IT development.
Korucuk et al., 2023	Picture fuzzy LBWA (evel based weight assessment)–CoCoSoframework	Economic indicators, environmental indicators, social indicators, and ideal smart network strategies	Developing an optimal smart network strategy.
Bouraima et al., 2023	IRN (interval rough numbers) SWARA and IRN CoCoSo model	National policy, railway network, human and institutional capacity, natural environment, and financial resources	Evaluation of the railway transportation system.
Zagorskas and Turskis, 2024	ARAS-G MCDM Approach	Population, travel distance, and financial savings	Enhance the connectivity of the cycling pathway network, highlighting the possibility of significant growth in cycling and walking.

In conclusion, there exists a body of research that examines the environmental factors in the concept of sustainability with multiple perspectives. Most of the studies only consider a single city or country with limited perspectives. However, in order to analyze sustainable transportation, it is required to consider many factors. Additionally, it is necessary that the method efficiently mitigates the impact of dimensions from both positive and negative viewpoints. In the present study, a total of 12 distinct criteria are taken into account for the purpose of addressing evaluation of European countries, implementing the GRA, Entropy Weight Method (EWM), and MABAC methods.

3. Methodology

3.1. Grey Relational Analysis (GRA)

Deng (J.-L. Deng, 1982) introduced the grey system theory, which specifically addressed the process of decision making when only partial knowledge is available and other aspects remain unclear (Patil et al., 2019). Grey theory is an effective framework employed to address situations characterized by uncertainty. The available information may encompass diverse uncertainties and distortions in the pursuit of novel systems with both internal and external impacts, as well as constraints on human comprehension (Erdemir & Kırkağaç, 2022). The GRA is a significant theory used to evaluate alternatives based on specific criteria (Mondal & Roy, 2022). Considering the GRA, there are a few studies conducted in the literature related to sustainable transportation. One such article aims to determine the most suitable mode or combination of modes for transporting shipments from the starting point to the destination (Fulzele et al., 2019). This is achieved by using an integrated approach that combines grey relational analysis based intuitionistic fuzzy multi-criteria decision-making process and a fuzzy multi-objective linear programming model. Another study presents a method for solving the problem of making decisions in the field of sustainable transportation investments and logistic service providers, where the criteria and expert weight information are unknown (Qadir et al., 2023). The proposed approach utilizes Pythagorean double hierarchy linguistic term sets and hierarchy linguistic term sets with grey relational analysis. Transportation sectors are crucial to guarantee the creation of environmentally friendly towns. In order to achieve this objective, another study constructed a complete assessment index system consisting of three subsystems, seven facets, and 31 indicators (F. Deng et al., 2020). Subsequently, the combination of entropy weight and gray correlation was employed to ascertain the weights of the indices. In this respect, another study accomplished three primary objectives (Yuan et al., 2017): investigation into the links between transportation development, energy consumption, and CO2 emissions in 30 Chinese provinces (determining the specific transportation development mode for each province). The study uncovered policy implications for promoting sustainable transportation development at the provincial level. The 30 provinces can be categorized into eight development modes based on the computed Grey Relational Grades.

The steps of GRA are given as follows (Mondal & Roy, 2022):

Step 1: The decision matrix is formed with n criteria and m alternatives. The value of each alternative for the relevant criterion is recorded in the X_{ij} matrix.

$$X_{ij} = [x_{ij}]_{mxn} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{1}$$

Step 2: In the first step, the normalization process is applied by using Eq. 2 and Eq. 3. Also, xij notation is used to record the value of each alternative for the relevant criterion.

When smaller, the better-quality characteristic, normalized value r_{ij} is given by:

$$r_{ij} = \frac{max_i(x_{ij}) - x_{ij}}{max_i(x_{ij}) - min_i(x_{ij})} \tag{2}$$

When larger, the better-quality characteristic, normalized value r_{ij} is given by:

$$r_{ij} = \frac{x_{ij} - min_i(x_{ij})}{max_i(x_{ij}) - min_i(x_{ij})} \tag{3}$$

where $max_i(x_{ij})$ and $min_i(x_{ij})$ are the maximum and minimum values of the original sequence r_{ij}.

Step 3: During the second stage, the deviation sequence is acquired by applying the subsequent equation:

$$\Delta_{ij} = max_i(r_{ij}) - r_{ij} \tag{4}$$

Step 4: The grey relational coefficient (GRC) is computed by Eq. 5.

$$\gamma_{ij} = \frac{min_i(\Delta_{ij}) + \gamma max_i(\Delta_{ij})}{\Delta_{ij} + \gamma max_i(\Delta_{ij})} \tag{5}$$

where γ is the resolving coefficient, $\gamma \epsilon [0,1]$.

Hence, the estimation of the grey relational grade (GRG) is as follows:

$$\delta_i = \Sigma_j w_j \gamma_{ij}, \forall i, \tag{6}$$

where w_j is the weight of j_{th} criterion, and $\sum_j w_j = 1$.

Therefore, The GRA method gives each indicator the same weight.

3.2. Entropy Weight Method (EWM)

The Entropy Weight Method (EWM) was proposed by Shannon (1948) in order to determine objective weights. EWM has a significant benefit over subjective weighting models as it eliminates the influence of human variables on indicator weights, hence improving the objectivity of the comprehensive evaluation results (Zhu et al., 2020). Entropy, which has its basis in probability theory, is utilized to evaluate ambiguous information. This method employs the entropy values of each indicator to calculate the weights of the indicators, making it an objective weighing approach (Madenoğlu, Ünlüsoy, & Yilmaz, 2022). Considering EWM, several studies in the literature have considered the transportation and sustainability perspectives. One such study aimed to produce a multi-objective model for optimizing the passenger transportation system, taking into account carbon emissions, transit costs, and resource usage (W. Zhang et al., 2023). Furthermore, the optimal solution was achieved by combining the ideal point approach with EWM. Another article constructs an evaluation index method for the urban comprehensive carrying capacity by selecting nine indicators from the population, economy, construction, and transportation aspects (Han et al., 2022). The urban comprehensive carrying capacity of the five provinces was calculated using the EWM and the Linear Weighted Sum Method. Another relevant paper analyzes the development of green transportation in Zhoushan as an example, selecting the data from three aspects: basic indicators, means of transportation, and road construction (Shen et al., 2021). The entropy weight method was used to determine the entropy value and weight of each index, establishing the index evaluation system. The steps of the EWM are outlined below.

Step 1: The decision matrix is formed with n criteria and m alternatives. The value of each alternative for the relevant criterion is recorded in the X_{ij} matrix, as in Eq. 1.

Step 2: Normalization matrix is calculated using Eq.7 to normalize the decision matrix for both minimization and maximization criteria.

$$e_{ij} = \frac{x_{ij}}{\Sigma_{i=1}^{m} x_{ij}} \tag{7}$$

Step 3: Entropy values of the criteria are calculated using Eq.8.

$$E_j = \frac{\Sigma_{i=1}^{m} e_{ij} ln(e_{ij})}{ln(m)} \tag{8}$$

Step 4: The weight of each criterion is calculated as follows:

$$w_j = \frac{1 - E_j}{\Sigma_{j=1}^{n}(1 - E_j)} \tag{9}$$

3.3. Multi-Attributive Border Approximation Area Comparison Method (MABAC)

MABAC is a MCDM method proposed by Pamucar et al. (2015). The approach considers the possible values of both loss and gain, with the outcomes not being affected by the dimensions or positive/negative angles of the criterion. Unlike other MCDM approaches, the MABAC method effectively counteracts the influence of dimensions from both positive and negative perspectives in the decision-making process (Shi et al., 2024). For the MABAC method, the existing literature focuses on transportation without considering sustainability. Other studies have also considered the MABAC method related to transportation. One of these works introduces a novel approach in the field of multi-criteria decision-making to identify optimal route criteria for the transportation of hazardous materials (Noureddine & Ristic, 2019). The weight coefficients of these criteria were derived using the Full Consistency Method. The evaluation and selection of vendors were carried out via the TOPSIS and MABAC methodologies. Another research focuses on the development of a selection strategy for hybrid automobiles utilizing the entropy-based MABAC approach (Biswas & Das, 2018). This study emphasizes the most optimal hybrid car that effectively mitigates air pollution in urban areas, while also providing notable environmental advantages, decreasing reliance on foreign energy imports, and minimizing annual fuel expenses. One of the studies related to MABAC application on transportation considers railway management (Veskovic et al., 2018). In this article, the railway management models in Bosnia & Herzegovina were examined. To assess these models, a novel hybrid model was utilized, namely a model that combines the Delphi, Step-Wise Weight Assessment Ratio Analysis, and MABAC methodologies. The last relevant study that we observed presents a thorough and sophisticated approach to data analytics for rating commercial service airports (Zhou et al., 2023). The methodology includes data envelopment analysis, the best-worst method, and the MABAC comparison method to provide a robust ranking framework.

Steps of MABAC method is as follows:

Step 1: Decision matrix is introduced. Eq. 6 demonstrates the first step.

Step 2: Normalization process is applied.

For a criterion that is beneficial and follows a “larger-the-better” criterion:

$$d_{ij} = \frac{x_{ij} - min(x_i)}{max(x_i) - min(x_i)} \tag{10}$$

For a criterion that is non-beneficial (cost) and follows a “smaller-the-better” criterion:

$$d_{ij} = \frac{x_{ij} - max(x_i)}{min(x_i) - max(x_i)} \tag{11}$$

Step 3: The weighted matrix is calculated using Eq. 12.

$$u_{ij} = w_j(d_{ij} + 1) \tag{12}$$

Step 4: The border approximation matrix is generated.

$$g_j = \frac{1}{m\sqrt{\prod_{i=1}^{m} u_{ij}}} \tag{13}$$

The border approximation area matrix (G) has been generated in a 1 × n format.

$$G = [g_1\, g_2\, \ldots g_n] \tag{14}$$

Step 5: Determine the distance between the alternatives and the border approximation area.

$$r_{ij} = u_{ij} - g_j \tag{15}$$

$$R = [r_{ij}]_{mxn} \tag{16}$$

where R indicates the distance matrix, the variable r_{ij} represents the distance between the i_{th} alternative and the j_{th} criterion, measured from the border approximation area.

Step 6: Ranking of the alternatives.

$$CF_i = \Sigma_{j=1}^{n} r_{ij} \tag{17}$$

where CF_i represents the value of the criteria function for the ith alternative, with a higher value indicating a better result.

4. Applications and Discussion

We have ranked European countries according to the sustainability of their transportation. Due to the availability of data, 25 out of 27 European countries have considered and compared under 12 criteria. The GRA and entropy MABAC methods were applied in order to rank the countries. Figure1 below shows the flowchart of the present research.

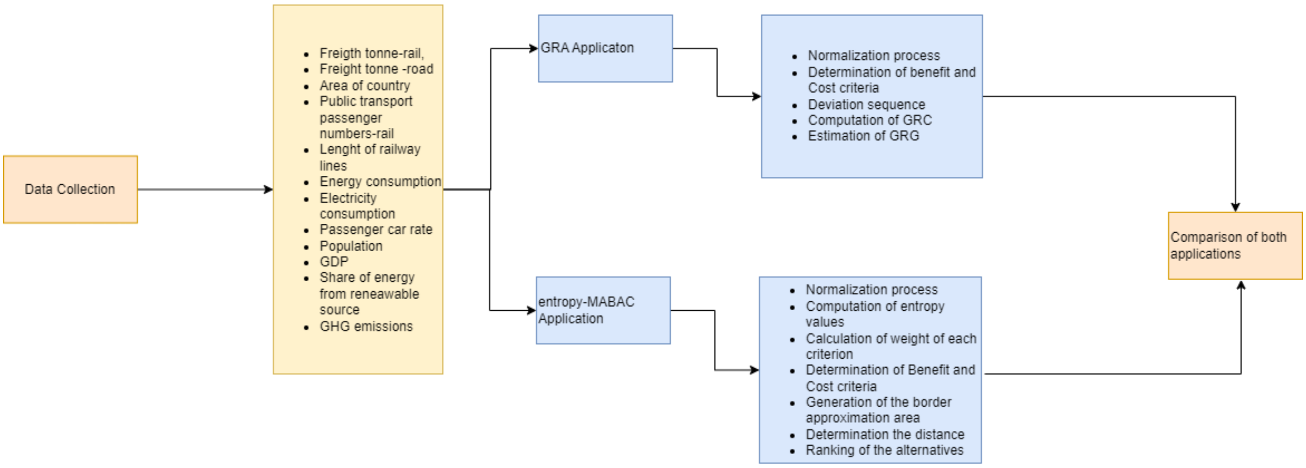

Figure 1. Flowchart of the present study

The data utilized has been acquired from multiple databases, as indicated in Table 2 below.

Table 2. Characteristics of data

Criteria	Database	Date / Reference	Relevance
Freight tonne-km by rail	OECD	2021/ (da Fonseca-Soares et al., 2024)	A decrease in the necessity of traveling in order to minimize the quantity of journeys.
Freight tonne-km by road	OECD	2021/ (Farid et al., 2024)	Reduced use of cars is required.
Area of country (sq.km)	European Union	2022/ (Di Martino et al., 2024)	Relevance of population density related to the social aspect of sustainable transportation.
Public transport passenger numbers by rail	OECD	2021 / (Kraus, 2021), (Şener; et al., 2023)	Reduced use of cars is required.
Length of railway lines (km)	UNECE	2021/ (Kraus, 2021)	Decreasing the necessity of travel to minimize the frequency of travels and the distance covered per trip
Energy consumption in transport	Eurostat	2021 / (Gulcimen et al., 2023)	Environmental aspect of sustainable transportation due to low carbon emission
Electricity consumption in transport (road)	Eurostat	2021 /(Armenta-Déu, 2024)	Environmental aspect of sustainable transportation due to low carbon emission

Table 2. Continued

Passenger car rate (per 1000 inhabitants)	UNECE	2021 / (Gulcimen et al., 2023)	Developing the concept of shared car ownership and promoting the use of reduced emission vehicles
Population size	World Bank	2021/ (Al-Shammari & Al-Jameel, 2023), (Antunes et al., 2023)	Developing the social and environmental relevance to transportation
Gross Domestic Product (GDP)	World Bank	2021 /(Antunes et al., 2023)	GDP has a crucial role in fostering the advancement of transportation due to investment opportunities.
Share of energy from renewable sources used in transport	Eurostat	2021/ (Kraus, 2021)	Environmental aspect of sustainable transportation due to low carbon emission
Total greenhouse gas emissions (GHG) (kt of CO2 equivalent)	World Bank	2019/ (Kraus, 2021)	Environmental aspect of sustainable transportation due to low carbon emission

A set of 12 indicators was employed to assess the sustainability of transportation in European countries. Criteria that provide benefit include: "Freight tonne-km by rail," "Public transport passenger numbers by rail," "Length of railway lines," "Electricity consumption in transport," "GDP," and "Share of energy from renewable sources used in transport." Non-benefit criteria (cost) were chosen as: "Freight tonne-km by road," "Area of country," "Energy consumption in transport," "Passenger car rate," "Population size," and "Total greenhouse gas emissions."

The basic data set is demonstrated in Table 3 below.

Table 3. Data set of the proposed study

	Freight tone km-rail	**Freight tone km-road**	**Area of country**	**Public transport passenger numbers-rail**	**Length of railway lines**	**Energy consumption in transportation**	**Electricity consumption in transportation**	**Passenger car rate**	**Population per area**	**GDP**	**Share of energy from renewable source**	**Total GHG emission**
Austria	21781	19564	83858.	218850	5603	7975.724	14.011	574	8955797	480368.4	9.355	76917.89
Belgium	6698	36199	30528	235000	3578	8531.358	254.4	511	11592952	594104.18	10.262	108064.9
Bulgaria	4658	35161	110993	17147	4031	3433.309	39.545	412	6877743	84056.31	7.613	51283.43
Croatia	3172	13629	56542	13541	2617	2147.878	7.1	454	3899000	68955.08	6.983	22257.68
Czech Republic	16326	63756	78866	135318	9523	6879.881	75.917	569	10505772	281777.89	7.492	116590.9
Denmark	1986	15354	43094	123918	1998	4009.141	234.951	476	5856733	398303.27	10.546	43200.04
Estonia	2124	5237	45228	6077	1167	841.386	16.859	621	1330932	37191.17	11.236	12873.96
Finland	10749	29618	338015	55009	5918	4023.794	236	657	5541017	297301.88	20.512	51478.64
France	35751	167247	55150	894397	27057	42693.98	792.64	568	67749632	2957879.76	8.209	414036
Germany	123067	307277	35703	2880871	38394	52299.14	1386	583	83196078	4259934.91	7.972	749708.7
Greece	490	20903	131957	10029	2339	5530.448	18.836	527	10641221	214873.88	4.31	78502.91
Hungary	11347	37101	93030	100730	7889	4897.618	84	414	9709891	181848.02	6.159	60586.46
Ireland	70	12485	70273	36892	2045	3709.981	63.195	460	5033165	504182.6	4.296	61475.62

Table 3. Continued

Italy	24262	144986	301337	491782	16832	35290.31	440.485	673	59109668	2107702.84	10.001	389003.8
Latvia	7367	15103	64589	11194	1859	1077.062	28.999	403	1884490	39853.5	6.436	11704.76
Lithuania	14566	57755	65300	3948	1910	2144.972	46.6	574	2800839	66445.26	6.462	18934.41
Luxemburg	207	6550	2586	16595	271	1770.925	21.585	686	640064	85506.24	7.962	10481.21
Netherlands	7188	70227	41526	207165	3041	9187.53	1071.285	503	17533044	1012846.76	8.991	172231.2
Poland	54387	379820	312685	240022	19287	23537.388	63.73	678	37747124	679444.83	5.665	353140.2
Portugal	2336	32075	91982	120702	2527	5474.286	17.537	547	10325147	253663.14	8.609	61380.97
Romania	13625	61848	238391	54937	10764	6879.222	179.229	398	19119880	284087.56	7.669	101236.3
Slovakia	8580	30138	49012	46345	3626	2619.259	25	458	5447247	116527.1	8.753	38063.21
Slovenia	4937	24968	20253	11860	1209	1799.603	3.731	564	2108079	61748.59	10.641	16463.32
Spain	10299	270172	505992	418501	16280	30350.056	350	526	47415750	1427380.68	9.194	306947
Sweden	23449	42685	449964	164490	10912	6850.677	1433	479	10415811	635663.8	30.426	46188.53

The GRA method was first implemented, employing equal weighting for all indicators. The grey degrees of relationships are defined by considering Equations 1-6. Figure 2 below demonstrates the ranking of European countries based on their GRA scores.

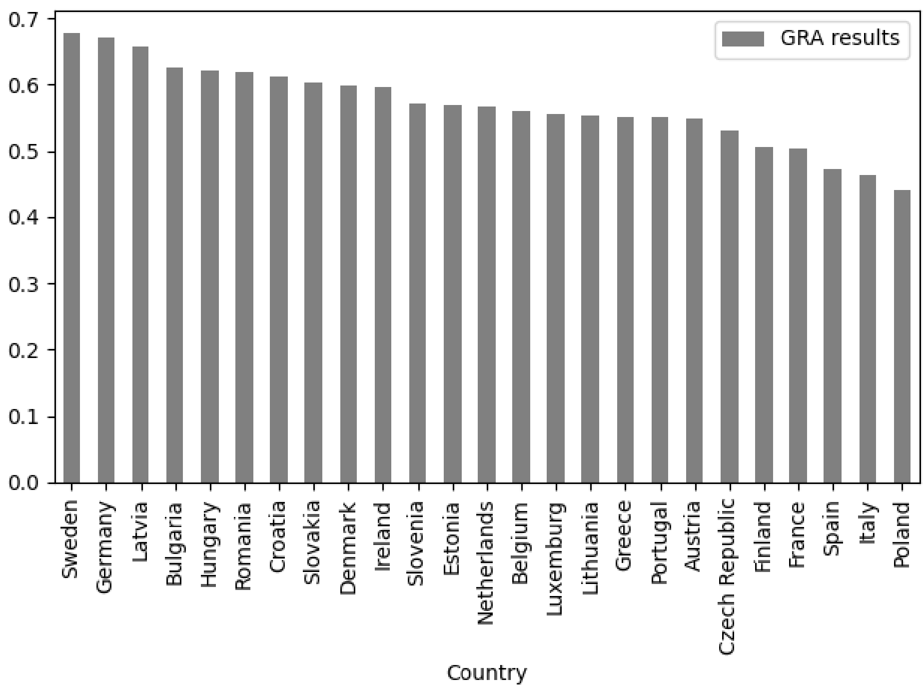

Figure 2. GRA results

As seen from Figure 2, Sweden in in the top position, whichs demonstrates a significant emphasis on the issue of sustainability in transportation. Germany and Latvia are not far from Sweden in terms of sustainability, followed by such countries as Bulgaria, Hungary, Romania, Croatia, and Slovakia, which all prioritize sustainability in transportation. Spain, Italy, and Poland appear are the lowest in terms of sustainability rankings. Following the implementation of the GRA method, the entropy MABAC approach was utilized for a comparative analysis. The weights of the criteria were determined using the entropy method (see Table 4). Equations 7, 8, and 9 were used for this purpose. The MABAC method was applied to rank the countries after determining the weights. The weights obtained from the entropy approach were then provided as input for the MABAC method. The ranking scores of the MABAC approach were derived using Equations 10-17. Figure 3 below displays the outcomes of the entropy-MABAC technique.

Table 4. The weights obtained via the Entropy method

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
0.052	0.103	0.099	0.098	0.082	0.102	0.120	0.042	0.049	0.099	0.049	0.104

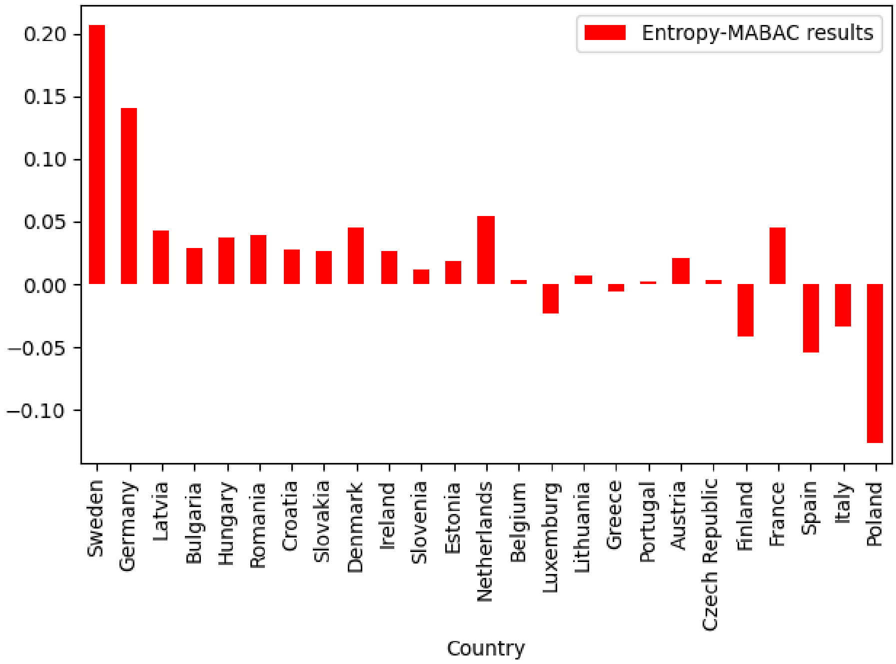

Figure 3. Results of the entropy-MABAC method

The ranking clearly shows that Sweden and Germany are at the top, followed by Latvia, Bulgaria, Hungary, and Romania, as depicted in Figure 3. Conversely, Spain, Italy, and Poland are ranked at the bottom. Luxemburg, Greece, Finland, Spain, Italy, and Poland belong to the lower approximation area. Sweden, Germany, Latvia, Bulgaria, Hungary, Romania, Croatia, Slovakia, Denmark, Ireland, Slovenia, Estonia, Netherlands, Belgium, Lithuania, Portugal, Austria, the Czech Republic, and France are in the upper approximation area. That said, Belgium, Greece, Portugal, and the Czech Republic are positioned nearer to the border approximation area.

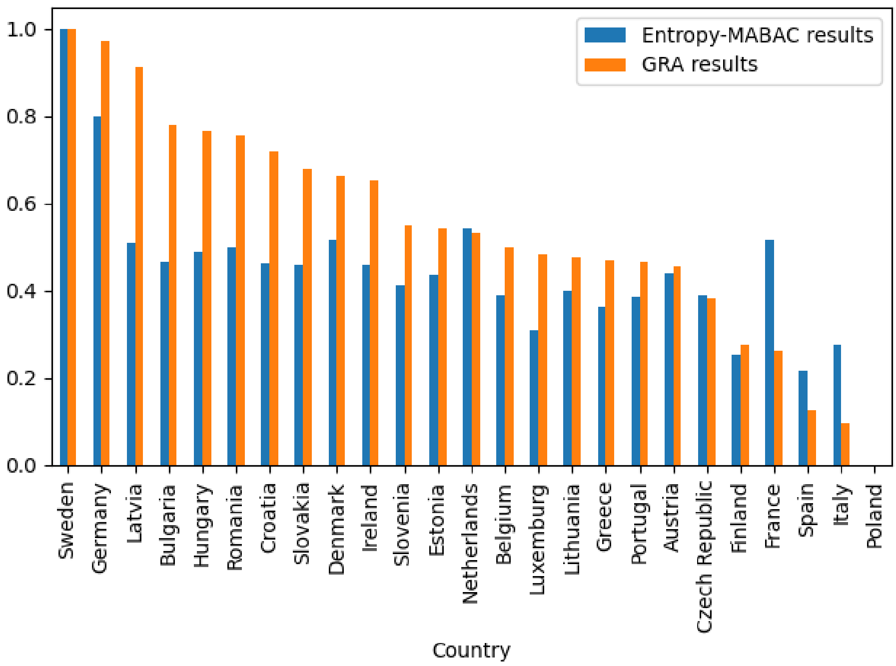

Figure 4. Comparison of the GRA and entropy-MABAC methods

Table 5. Ranking scores for both methods

Country	GRA Scores	Ranking	Entropy-MABAC Scores	Ranking
Sweden	0.677672984	1	0.206114279	1
Germany	0.671453793	2	0.140075211	2
Latvia	0.656852384	3	0.043343855	6
Bulgaria	0.625476172	4	0.028955110	9
Hungary	0.622181711	5	0.036776235	8
Romania	0.619843557	6	0.040024224	7
Croatia	0.611199333	7	0.028111785	10
Slovakia	0.602009995	8	0.026648492	11
Denmark	0.598231028	9	0.045847793	4
Ireland	0.595832747	10	0.026352755	12
Slovenia	0.571035146	11	0.011496918	15
Estonia	0.56972317	12	0.019146209	14
Netherlands	0.56755178	13	0.054080758	3
Belgium	0.559279733	14	0.003746736	17
Luxemburg	0.555484983	15	-0.023347558	21
Lithuania	0.553393229	16	0.0069819407	16
Greece	0.551904939	17	-0.0051815584	20
Portugal	0.551330777	18	0.0026556879	19
Austria	0.548821688	19	0.0204861352	13
Czech Republic	0.531790046	20	0.0030515801	18
Finland	0.506155845	21	-0.0416358529	23
France	0.503617347	22	0.04530044124	5
Spain	0.471180761	23	-0.05396344832	24
Italy	0.463661207	24	-0.03360571062	22
Poland	0.440949769	25	-0.12591610324	25

As illustrated in Figure 4, the min-max scale application was implemented on the data in order to compare the GRA and entropy-MABAC results. When compared to the results of the GRA and entropy-MABAC methods, it can be seen from Figure 4 and Table 5 that the ranking is similar to each other. The implementation of a correlation analysis between the GRA scores and entropy-MABAC scores was also carried out. The correlation study yielded a coefficient of 0.8218, which is near to 1. This indicates a significant relationship between the results produced from GRA and entropy-MABAC, suggesting that the outputs from both methods are consistent. According to both results, Sweden and Germany rank first and second, respectively. Poland is ranked at the bottom for both methods. While there may be variations in the ranking of the top, intermediate, and bottom countries, their alignments display similar attributes. On the other hand, France and Netherland attain a higher ranking in the entropy-MABAC method as opposed to the GRA approach, which ranks them near the bottom. Both approaches demonstrate that Sweden and Germany prioritize sustainability in the transportation category, while Poland, Spain, and Italy lag behind in this regard.

4.1. Managerial implications

- Decision makers can utilize these results as a standard to compare their country's performance with that of other countries. Countries such as Sweden and Germany, that ranked high in both the GRA and entropy-MABAC scores, might be considered as models for implementing effective strategies in sustainable transportation. This can facilitate the identification of areas for improvement.
- Policy and investment decisions can be prioritized by decision-makers using the criteria provided in the study. For example, countries such as Latvia and Bulgaria demonstrate reasonably GRA rankings but rank lower in entropy-MABAC scores, highlighting the necessity for targeted efforts to address the identified vulnerabilities.
- Countries that have higher rankings can utilize their expertise and capabilities to encourage the transfer of knowledge and collaboration with countries that have lower rankings. This can result in the use of the right techniques and expedite advancements towards objectives of sustainable transportation.

5. Conclusion

GRA is extensively utilized for the examination of complicated situations. In addition, the entropy weight method offers a notable advantage compared to subjective weighting models by removing the impact of human factors on indicator weights, hence enhancing the objectivity of the comprehensive evaluation outcomes. In addition, the MABAC method successfully mitigates the impact of dimensions, whether positive or negative, in the decision-making process, distinguishing it from other MCDM approaches. Given the effective handling of uncertainties by all these methods, the present research compared the GRA and Entropy-MABAC methodologies. This paper describes several uses of the GRA and entropy-MABAC approaches. Researchers and policymakers are exploring new techniques in response to the growing demand for sustainable transportation systems. European countries, characterized by their varied terrains and differing population densities, have placed significant emphasis on enhancing the transportation infrastructure to attain sustainability objectives. This research examines the significance of using both GRA and entropy-MABAC methods in the transportation system of European countries, with a particular focus on sustainability.

The proposed research involves a comparison of 25 European countries based on 12 criteria, with data gathered from diverse sources. As can be understood from the results of the present analysis, there are similarities in the ranking of the GRA and entropy-MABAC methods. According to the results of the two methods, both Sweden and Germany demonstrate a strong commitment to sustainability in the transportation category, while Poland, Spain, and Italy rank at the bottom. Further studies can expand the range of data and enable comparisons across a greater number of countries.

To summarize, although this study provides vital insights on sustainable transportation practices in European countries and presents a strong evaluation methodology, it is important to recognize certain limitations. The findings of the study depend on the presence and accuracy of data about transportation sustainability indices in the chosen European countries. Differences in the availability and reliability of data between countries can lead to biases or restrictions in the study. The analysis of the study relies on a singular temporal representation of facts at a precise point. Transportation systems and sustainability practices are dynamic and susceptible to modification throughout time. Therefore, the results may not accurately represent the long-term patterns or changing dynamics related to transportation sustainability.

Peer Review: Externally peer-reviewed.Peer Review

Author Contributions: Conception/Design of Study- İ.M.E., N.E.; Data Acquisition- İ.M.E., N.E.; Data Analysis/ Interpretation- İ.M.E., N.E.; Drafting Manuscript- İ.M.E., N.E.; Critical Revision of Manuscript- İ.M.E., N.E.; Final Approval and Accountability- İ.M.E., N.E.

Conflict of Interest: Authors declared no conflict of interest.

Financial Disclosure: Authors declared no financial support.

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REFERENCES

Al-Shammari, A., & Al-Jameel, H. (2023). Evaluation of the Selected Sustainable Indicators for Urban Roads Network: Al-Kufa City as a Case Study. *IOP Conference Series: Earth and Environmental Science, 1232*(1). https://doi.org/10.1088/1755-1315/1232/1/012051

Amekudzi, A. A., Jotin Khisty, C., & Khayesi, M. (2009). Using the sustainability footprint model to assess development impacts of transportation systems. *Transportation Research Part A: Policy and Practice, 43*(4), 339–348. https://doi.org/10.1016/j.tra.2008.11.002

Antunes, J., Tan, Y., Wanke, P., & Jabbour, C. J. C. (2023). Impact of R&D and innovation in Chinese road transportation sustainability performance: A novel trigonometric envelopment analysis for ideal solutions (TEA-IS). *Socio-Economic Planning Sciences, 87*(PA), 101544. https://doi.org/10.1016/j.seps.2023.101544

Armenta-Déu, C. (2024). Improving Sustainability in Urban and Road Transportation: Dual Battery Block and Fuel Cell Hybrid Power System for Electric Vehicles. *Sustainability (Switzerland)* , 16(5). https://doi.org/10.3390/su16052110

Babaei, A., Khedmati, M., & Jokar, M. R. A. (2022). A New Model for Evaluation of the Passenger and Freight Transportation Planning Based on the Sustainability and Safety Dimensions: A Case Study. *Process Integration and Optimization for Sustainability, 6*(4), 1201–1229. https://doi.org/10.1007/s41660-022-00272-0

Biswas, T. K., & Das, M. C. (2018). Selection of hybrid vehicle for green environment using multi-attributive border approximation area comparison method. *Management Science Letters, 8*(2), 121–130. https://doi.org/10.5267/j.msl.2017.11.004

Bouraima, M. B., Qiu, Y., Stević, Ž., & Simić, V. (2023). Assessment of alternative railway systems for sustainable transportation using an integrated IRN SWARA and IRN CoCoSo model. *Socio-Economic Planning Sciences, 86*(November 2022). https://doi.org/10.1016/j.seps.2022.101475

da Fonseca-Soares, D., Eliziário, S. A., Galvincio, J. D., & Ramos-Ridao, A. F. (2024). Greenhouse Gas Emissions in Railways: Systematic Review of Research Progress. *Buildings, 14*(2), 1–22. https://doi.org/10.3390/buildings14020539

Deng, F., Fang, Y., Xu, L., & Li, Z. (2020). Tourism, Transportation and Low-Carbon City System Coupling Coordination DegreeA Case Study in Chongqing Municipality, China. *International Journal of Environmental Research and Public Health, 17*(3). https://doi.org/10.3390/ijerph17030792

Deng, J.-L. (1982). Control Problems of Grey Systems. *Systems & Control Letters, 1*(5), 288–294.

Di Martino, A., Longo, M., & Foiadelli, F. (2024). Increasing transportation sustainability from scratch: Small city context. *Energy Conversion and Management, 304*(February), 118211. https://doi.org/10.1016/j.enconman.2024.118211

Ecer, F., Küçükönder, H., Kayapınar Kaya, S., & Faruk Görçün, Ö. (2023). Sustainability performance analysis of micro-mobility solutions in urban transportation with a novel IVFNN-Delphi-LOPCOW-CoCoSo framework. *Transportation Research Part A: Policy and Practice, 172*(April). https://doi.org/10.1016/j.tra.2023.103667

Erdemir, Ö. K., & Kırkağaç, M. (2022). A Comparative Study on Performance of Insurance Companies with Grey Relational Analysis and Analytic Hierarchy Process. *Alanya Akademik Bakış, 6*(3), 2627–2645. https://doi.org/10.29023/alanyaakademik.1070741

Farid, H. M. A., Dabic-Miletic, S., Riaz, M., Simic, V., & Pamucar, D. (2024). Prioritization of sustainable approaches for smart waste management of automotive fuel cells of road freight vehicles using the q-rung orthopair fuzzy CRITIC-EDAS method. *Information Sciences, 661*(July 2023), 120162. https://doi.org/10.1016/j.ins.2024.120162

Fulzele, V., Shankar, R., & Choudhary, D. (2019). A model for the selection of transportation modes in the context of sustainable freight transportation. *Industrial Management and Data Systems, 119*(8), 1764–1784. https://doi.org/10.1108/IMDS-03-2019-0169

Gamal, A., Abdel-Basset, M., Hezam, I. M., Sallam, K. M., & Hameed, I. A. (2023). An Interactive Multi-Criteria Decision-Making Approach for Autonomous Vehicles and Distributed Resources Based on Logistic Systems: Challenges for a Sustainable Future. *Sustainability (Switzerland), 15*(17). https://doi.org/10.3390/su151712844

Gökçekuş, H., Ozsahin, D. U., & Al-Othman, D. (2019). Evaluation of the impact of sustainable transportation alternatives on environment using fuzzy PROMETHEE method. *International Journal of Innovative Technology and Exploring Engineering, 8*(8), 3254–3259.

Gulcimen, S., Aydogan, E. K., & Uzal, N. (2023). Robust Multicriteria Sustainability Assessment in Urban Transportation. *Journal of Urban Planning and Development, 149*(2), 4090. https://doi.org/10.1061/jupddm.upeng-4090

Han, C., Zheng, J., Lu, B., & Yu, D. (2022). Analysis on Influencing Factors of urban comprehensive carrying capacity: a case study of five provinces in Northwest China. *International Conference on Geoinformatics, 2022-Augus*, 1–6. https://doi.org/10.1109/Geoinformatics57846.2022.9963843

Heidary Dahooie, J., Mohammadian, A., Qorbani, A. R., & Daim, T. (2023). A portfolio selection of internet of things (IoTs) applications for the sustainable urban transportation: A novel hybrid multi criteria decision making approach. *Technology in Society, 75*(May), 102366. https://doi.org/10.1016/j.techsoc.2023.102366

Hsiao, S. W., Lin, H. H., & Ko, Y. C. (2017). Application of grey relational analysis to decision-making during product development. Eurasia Journal of Mathematics, *Science and Technology Education, 13*(6), 2581–2600. https://doi.org/10.12973/EURASIA.2017.01242A

Illahi, U., & Mir, M. S. (2019). *Sustainable Transportation: Indicators, Frameworks, and Performance Management.* Springer-Verlag, Heidelberg, Germany.

Jiang, F., Ma, L., Broyd, T., Li, J., Jia, J., & Luo, H. (2023). Systematic framework for sustainable urban road alignment planning. *Transportation Research Part D: Transport and Environment, 120*(May), 103796. https://doi.org/10.1016/j.trd.2023.103796

Johnson, B. J., & White, S. S. (2010). Promoting Sustainability through Transportation Infrastructure? Innovation and Inertia in the Kansas City Metropolitan Area. *Journal of Urban Planning and Development, 136*(4), 303–313. https://doi.org/10.1061/(asce)up.1943-5444.0000027

Karjalainen, L. E., & Juhola, S. (2019). Framework for assessing public transportation sustainability in planning and policy-making. *Sustainability (Switzerland)*, 11(4). https://doi.org/10.3390/su11041028

Korucuk, S., Aytekin, A., Ecer, F., Pamucar, D. S. S., & Karamaşa, Ç. (2023). Assessment of ideal smart network strategies for logistics companies using an integrated picture fuzzy LBWA–CoCoSo framework. *Management Decision, 61*(5), 1434–1462. https://doi.org/10.1108/MD-12-2021-1621

Kovač, M., Tadić, S., Krstić, M., & Veljović, M. (2023). A Methodology for Planning City Logistics Concepts Based on City-Dry Port Micro-Consolidation Centres. *Mathematics, 11*(15). https://doi.org/10.3390/math11153347

Kraus, L. (2021). Sustainable Urban Transportation Criteria and Measurement — A Systematic Literature Review. *Sustainability, 13*(7113).

Lev-On, M., Shapiro, E., & Cox, R. (2005). The partnership for clean fuels and vehicles: A new approach to helping countries achieve environmental sustainability in the transportation sector. *SAE Technical Papers*, 114(2005), 196–205. https://doi.org/10.4271/2005-01-0538

Liu, S., Forrest, J., & Vallee, R. (2009). Emergence and development of grey systems theory. *Kybernetes, 38*(7), 1246–1256. https://doi.org/10.1108/03684920910976943

Madenoğlu, F. S., Ünlüsoy, Ö. F., & Yılmaz, Ç. (2022). Performance Evaluation of Energy Companies With a Novel Integrated Multi-Criteria Decision Making Method. *Kafkas Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 13*(26), 640–658. https://doi.org/10.36543/kauiibfd.2022.027

Mondal, A., & Roy, S. K. (2022). Application of Choquet integral in interval type-2 Pythagorean fuzzy sustainable supply chain management under risk. *International Journal of Intelligent Systems, 37*(1), 217–263. https://doi.org/10.1002/int.22623

Noureddine, M., & Ristic, M. (2019). Route planning for hazardous materials transportation: Multi-criteria decision-making approach. *Decision Making: Applications in Management and Engineering, 2*(1), 66–85. https://doi.org/10.31181/dmame1901066n

Palander, T., Haavikko, H., Kortelainen, E., & Kärhä, K. (2020). Comparison of energy efficiency indicators of road transportation for modeling environmental sustainability in "green" circular industry. *Sustainability (Switzerland), 12*(7), 1–22. https://doi.org/10.3390/su12072740

Pamučar, D., & Ćirović, G. (2015). The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC). *Expert Systems with Applications, 42*(6), 3016–3028. https://doi.org/10.1016/j.eswa.2014.11.057

Patil, A. N., Walke, G., & Gawkhare, M. (2019). Grey Relation Analysis Methodology and its Application. RESEARCH REVIEW International

Journal of Multidisciplinary, 3085(February), 409–411. https://doi.org/10.5281/zenodo.2578088

Qadir, A., Alghaffari, S. N., Abosuliman, S. S., & Abdullah, S. (2023). A three-way decision-making technique based on Pythagorean double hierarchy linguistic term sets for selecting logistic service provider and sustainable transportation investments. *AIMS Mathematics, 8*(8), 18665–18695. https://doi.org/10.3934/math.2023951

Rani, P., Alrasheedi, A. F., Mishra, A. R., & Cavallaro, F. (2023). Interval-valued Pythagorean fuzzy operational competitiveness rating model for assessing the metaverse integration options of sharing economy in transportation sector. *Applied Soft Computing, 148*, 110806. https://doi.org/10.1016/j.asoc.2023.110806

Rehman, F. U., Islam, M. M., & Miao, Q. (2023). Environmental sustainability via green transportation: A case of the top 10 energy transition nations. *Transport Policy, 137*(April), 32–44. https://doi.org/10.1016/j.tranpol.2023.04.013

Rogers, M. M., & Weber, W. L. (2011). Evaluating CO2 emissions and fatalities tradeoffs in truck transport. *International Journal of Physical Distribution and Logistics Management, 41*(8), 750–767. https://doi.org/10.1108/09600031111166410

Santos-Arteaga, F. J., Di Caprio, D., Tavana, M., & Tena, E. C. (2023). A Credibility and Strategic Behavior Approach in Hesitant Multiple Criteria Decision-Making With Application to Sustainable Transportation. *IEEE Transactions on Fuzzy Systems, 3*1(2), 460–474. https://doi.org/10.1109/TFUZZ.2022.3188875

Senapati, T., Simic, V., Saha, A., Dobrodolac, M., Rong, Y., & Tirkolaee, E. B. (2023). Intuitionistic fuzzy power Aczel-Alsina model for prioritization of sustainable transportation sharing practices. *Engineering Applications of Artificial Intelligence, 119*(November 2022), 105716. https://doi.org/10.1016/j.engappai.2022.105716

Şener, F., Aydoğan, S., & Akay, D. (2023). Urban Mobility Patterns with Linguistic Summarization: Insights from the Bicycle- Sharing System. *Erciyes University Journal of Institue Of Science and Technology, 39*(3), 538–547.

Shen, Z., Zhao, Q., & Fang, Q. (2021). Analysis of green traffic development in zhoushan based on entropy weight topsis. *Sustainability (Switzerland)*, 13(14), 1–13. https://doi.org/10.3390/su13148109

Shi, M., Li, X., & Xu, C. (2024). Two-stage site selection of hydrogen refueling stations coupled with gas stations considering cooperative effects based on the CRITIC-ITFAHP-MABAC method: A case study in Beijing. *International Journal of Hydrogen Energy*, 49, 1274–1292. https://doi.org/10.1016/j.ijhydene.2023.09.168

Soni, A. R., Amrit, K., & Shinde, A. M. (2022). COVID-19 and transportation of India: influence on infection risk and greenhouse gas emissions. *Environment, Development and Sustainability*, 0123456789. https://doi.org/10.1007/s10668-022-02311-9

Veskovic, S., Stevic, Ž., Stojic, G., Vasiljevic, M., & Milinkovic, S. (2018). Evaluation of the railway management model by using a new integrated model delphi-swara-mabac. *Decision Making: Applications in Management and Engineering*, 1(2), 34–50. https://doi.org/10.31181/dmame1802034v

Yuan, C., Wu, D., & Liu, H. (2017). Using grey relational analysis to evaluate energy consumption, CO2 emissions and growth patterns in China's provincial transportation sectors. *International Journal of Environmental Research and Public Health, 14*(12).

Zagorskas, J., & Turskis, Z. (2024). Enhancing Sustainable Mobility: Evaluating New Bicycle and Pedestrian Links to Car-Oriented Industrial Parks with ARAS-G MCDM Approach. *Sustainability (Switzerland) , 16*(7). https://doi.org/10.3390/su16072994

Zhang, L., & Hua, X. (2023). Evaluating efficiency of railway transportation based on cross-efficiency evaluation method and relative entropy evaluation method in China. *IET Intelligent Transport Systems, 17*(12), 2410–2418. https://doi.org/10.1049/itr2.12420

Zhang, W., Song, Y., Zhou, G., Song, Z., & Xi, C. (2023). Multiobjective-Based Decision-Making for the Optimization of an Urban Passenger Traffic System Structure. *Sustainability (Switzerland), 15*(18). https://doi.org/10.3390/su151813644

Zhou, Y., Kundu, T., Goh, M., Chakraborty, S., & Bai, X. (2023). A multi-stage multi-criteria data analytics approach to rank commercial service airports. *Journal of Air Transport Management, 111*(December 2021), 102410. https://doi.org/10.1016/j.jairtraman.2023.102410

Zhu, Y., Tian, D., & Yan, F. (2020). Effectiveness of Entropy Weight Method in Decision-Making. *Mathematical Problems in Engineering*, 2020, 1–5. https://doi.org/10.1155/2020/3564835

How cite this article

Eligüzel, İ.M., & Eligüzel, N. (2024) Evaluation of sustainable transportation in 25 european countries using GRA and entropy MABAC. *Journal of Transportation and Logistics, 9*(2), 245-259. https://doi.org/10.26650/JTL.2024.1437521