

REGIONAL DISPARITIES IN ROAD TRANSPORT DEVELOPMENT: A TOPSIS-BASED ANALYSIS OF POLAND

Paweł R. KOZUBEK¹, Dorota MIŁEK^{2*}

¹ Kielce University of Technology; p.kozubek@tu.kielce.pl, ORCID: 0000-0002-4471-0579

² Kielce University of Technology; dorothy@tu.kielce.pl, ORCID: 0000-0002-2358-4614

* Correspondence author

Purpose: The paper examines regional disparities in road transport development across Polish voivodeships over the 2010-2023 period, aiming to identify the scale and dynamics of spatial differentiation in this sector.

Design/methodology/approach: The study employs the TOPSIS multi-criteria decision-making method to construct a composite index of road transport development based on 25 diagnostic indicators grouped into six thematic areas. The analysis covers all 16 Polish voivodeships in two reference years: 2010 and 2023.

Findings: The results indicate persistent regional disparities, though with a modest trend towards convergence. The highest-ranking regions – Małopolskie, Śląskie, and Wielkopolskie – retained their leading positions, while the most notable improvements were recorded in Podlaskie. Key development drivers include infrastructure density, fleet structure, public transport availability, and investment share.

Research limitations/implications: The study is limited by the availability and consistency of regional data across the analysed years. Future research could extend the comparative perspective to other EU countries or explore causal links between transport development and socio-economic indicators.

Practical implications: The findings provide a robust analytical basis for regional transport policy and investment prioritisation. They support the formulation of targeted strategies aimed at reducing spatial inequalities and enhancing transport accessibility.

Social implications: By identifying risks of transport exclusion and access gaps, the study contributes to the discussion on social cohesion and regional equity in the development of the road transport system.

Originality/value: The paper offers a comprehensive, data-driven assessment of road transport development at the regional level in Poland, filling a research gap by integrating infrastructure, vehicle stock, and transport service indicators into a unified evaluation framework.

Keywords: spatial disparities, road transport, multicriteria evaluation, TOPSIS, transport policy.

Category of the paper: Research paper.

1. Introduction

Transport is a key sector in socio-economic development at both national and regional levels. In addition to enabling the exchange of goods and services, it shapes the spatial distribution of economic activity and population, fulfils socially essential functions, and plays a strategic role for the state (Kozłak, 2007). Its performance affects regional competitiveness and quality of life (Ejdys, 2017). An efficient transport system fosters spatial integration, links labour and consumer markets, and reduces development barriers in peripheral areas (Czernicki, Wacek, 2019).

Road transport plays a crucial role in Poland's transport system. Despite the growing importance of rail transport in recent years for collective passenger travel, road transport remains dominant in freight carriage and daily individual travel. Road transport is an integrator within the national transport system, connecting its various components (urban and regional transport), linking them with other modes of transport (including intermodal transport), and determining the spatial flows of people and goods. It should also be noted that, as the mode of transport with the broadest coverage and accessibility, road transport also places significant burdens on infrastructure and the environment.

Considerable disparities – especially in terms of transport infrastructure – can be observed in how road networks have evolved across different regions of Poland. This is due to multiple factors: the degree of urbanisation, the distribution of economic centres, the investment activity of local governments, and the historical layout of the road network (Karolewski, Roman, 2021). Analysing these disparities allows for assessing transport policy effectiveness and identifying development barriers within individual voivodeships.

Assessing and comparing the level of road transport development at the regional level requires consideration of numerous indicators related to infrastructure, transport enterprises, the volume of both passenger and freight transport, road safety, and the operation of urban public transport. Such a comprehensive approach makes it possible to accurately assess the quality and development of road transport and its impact on regional development.

Previous studies have primarily focused on analysing individual aspects of road transport, such as infrastructure conditions, levels of private motorisation, or the operation of passenger transport. However, there is a lack of comprehensive research that would integrate the wide range of factors related to the development of road transport at the voivodeship level. Identifying this research gap justifies the need to address this issue in the present study.

This article assesses spatial differentiation in the level of road transport development across Polish voivodeships in 2010 and 2023. The study applies the multi-criteria decision analysis method TOPSIS, which enables a synthetic evaluation and ranking of voivodeships regarding selected diagnostic indicators. These indicators are grouped into six key areas: transport enterprises, road infrastructure, vehicle fleet, freight and passenger transport, urban transport,

and road safety. The key research questions are: What are the differences in road transport development levels between Polish voivodeships? Which factors have the most significant impact on these differences? Has the disparity decreased or increased between 2010 and 2023?

These results may offer valuable insights for other EU countries facing similar regional disparities in the development of road transport. They also provide a basis for further discussion on the role of cohesion funding and regional strategies supporting transport accessibility.

2. Literature review

The transport system is one of the fundamental factors influencing the socio-economic development of regions. An efficient transport system is crucial for economic growth and social integration, while improvements in transport accessibility lead to increased economic activity and help prevent social exclusion (Czernicki, Wacek, 2019). Transport investments enhance regions' attractiveness, generate economic activity, and stimulate further investments, thereby contributing to regional GDP growth and urban development (Pokharel, Bertolini, te Brömmelstroet, 2023). Research often emphasises the importance of transport infrastructure and investments in this sector, which improve accessibility and may lead to economic production growth and overall development (Rokicki et al., 2021). However, the nature of these impacts is bidirectional: transport networks are shaped by population density and financial resources, which influence regional development (Yang et al., 2022). Similar conclusions have been drawn in international studies, which highlight the key role of transport infrastructure in enhancing competitiveness, promoting regional economic growth, and reducing spatial inequalities in EU and OECD member states. That said, the effects of infrastructure investment on cohesion, competitiveness, and development are neither linear nor uniform (Cigu et al., 2019; Nogués, González-González, 2022; Ferrarini, Muzzioli, De Baets, 2024).

The literature presents various approaches to defining the transport system, reflecting the complexity of this phenomenon. J. Kurowski points out that historical and political conditions, such as periods of central planning, have influenced the formation and definition of the transport system in Poland, differing from approaches used in other countries with different historical and political contexts. Moreover, some studies from other countries focus mainly on infrastructure or analyse the transport system primarily from a technical perspective, which may result in an incomplete understanding of its complexity (Kurowski, 2017). M. Falkowski and M. Pytel (2013) address this issue of definitional diversity, proposing that a transport system should be understood as a set of technical, organisational, and human elements that work together to enable the effective movement of people and goods across time and space. Thus, the transport system is an integrated whole comprising infrastructure, means of transport, organisation of transport services, and users with their transport needs. The individual

components of the transport system are strongly interdependent (Falkowski, Pytel, 2013), meaning that changes in one area (e.g., infrastructure) affect transport efficiency, safety, and territorial accessibility. Additionally, the interactions within the transport system refer to the integration and coordinated functioning of various transport modes to ensure the smooth movement of people and goods from one place to another. This concept forms the basis of “door-to-door” transport services, improving transport networks' efficiency and user-friendliness. One of the key manifestations of such integration is intermodality, defined as a transport system enabling the integrated use of at least two different transport modes within a single transport chain. Intermodality also indicates the quality of cooperation between various branches of transport (Janic, Reggiani, 2001). In this context, road transport plays a special role, functioning both as an independent transport branch and a key component of intermodal transport chains.

Road transport is distinguished by its availability, flexibility, and universal capabilities, which determine its dominant role within national and regional transport systems. As a basic mode of transport, it plays a vital role in economic development. However, its importance and impact on socio-economic processes vary spatially depending on geographical conditions, the level of urbanisation, and infrastructure availability (Gajewski, 2024). By enabling the efficient flow of goods and people, road transport supports economic activity and meets social needs in education, healthcare, and tourism (Falkowski, Pytel, 2013). Moreover, increasing spatial accessibility and mobility significantly contributes to regional development and the reduction of territorial barriers (Masárová, Ivanová, 2016). The performance of road transport is closely correlated with GDP growth, further emphasising its fundamental role in shaping the dynamics of regional development (Poliak et al., 2023).

The scale and quality of road transport's impact on regional socio-economic development largely depend on the state and availability of road infrastructure. Research confirms that the influence of road transport on socio-economic development is strongly related to the accessibility and quality of road infrastructure. Well-developed infrastructure increases regional attractiveness, facilitates the flow of goods and people, stimulates economic activity, and creates the conditions for sustainable socio-economic growth (Prus, Sikora, 2021; Pokharel, Bertolini, te Brömmelstroet, 2023).

For example, studies conducted in China, including southern Xinjiang (Li, Liu, Peng, 2018; Li et al., 2024) and regions with varying levels of development such as Jiang-Zhe-Hu and Yun-Gui-Chuan (Li, Liu, Peng, 2018), have shown significant links between the infrastructure condition and economic growth dynamics. These relationships have also been confirmed in India (Visakhapatnam region and the northeastern mountainous region) (Agnihotri, Tripathi, 2023; Jain, Sesidhar, Gupta, 2023) as well as in Turkey, where spatial effects of transport infrastructure investments have been observed (Elburz, Cubukcu, 2021). In the European Union, comparative studies have shown that investments in road infrastructure have a positive impact on economic growth, especially in countries with high levels of corruption control

(Butkus, Mačiulytė-Šniukienė, Matuzevičiūtė, 2023), contribute to economic convergence and spatial cohesion (Del Bo, Del Massimo, 2008; Rokicki et al., 2021; Wornalkiewicz, Kaplunovska, Padchenko, 2021). For example, Gaus and Link (2020) show that road infrastructure investments significantly boost economic output at county level in Germany. Similarly, Antonescu and Florescu (2024) document how regional infrastructure disparities in Romania contribute to persistent uneven economic development and impede territorial cohesion.

Beyond its economic impact, road infrastructure itself has been the subject of numerous studies focusing on its development patterns and spatial disparities. Burghardt et al. (2022) studied the historical development of road networks in U.S. cities and counties, highlighting substantial differences in urban and rural dynamics over more than a century and their influence on urban-rural relations. Similar issues were identified in northeastern India, with very low road density and significant variation between states and districts (Nandy, 2014; Koner, Bhadury, Purandare, 2022). The authors emphasise that improving road accessibility is crucial for overcoming development barriers and integrating the region with the rest of the country within the “Act East” policy framework¹. In Central Europe, substantial differences in road infrastructure development were noted in Slovakia and Poland, where comparative analysis showed strong correlations between infrastructure quality, geographic location, historical conditions, and investment policies between 2005 and 2013 (Masárová, Ivanová, 2016). Research conducted for Poland for the period 2004-2021 confirmed the existence of considerable regional disparities in road infrastructure development and pointed to the need for strategic approaches in infrastructure planning and management (Luty, Ziolo, 2015; Bekisz, Kruszyński, 2021; Karolewski, Roman, 2021; Poplawski et al., 2024). The development of road infrastructure in Poland between 1989 and 2018 was uneven: initially limited by financial constraints and the lack of long-term investment programmes, it accelerated only after the acquisition of European Union funds, which led primarily to the expansion of the road network, including the construction of motorways and expressways (Kozubek, 2019).

In addition to infrastructure studies, research on road transport development in Poland has also analysed private motorisation levels, passenger transport volumes, and road safety issues. Studies have revealed considerable spatial differentiation in private motorisation levels between 2005 and 2019, linked to public transport availability and demographic and economic factors (Kudłak, Kisiała, Kolsut, 2023). At the same time, a decline in collective transport availability, especially in rural and suburban areas, has led to an increased reliance on private transport and exacerbated transport exclusion (Wiśniewski, 2015; Czernicki, Wacek, 2019). These findings complement the overall understanding of road transport development, including changes in travel behaviour and access to road transport resources.

¹ The “Act East” policy was announced by the Government of India in 2014 as a continuation of the earlier “Look East” strategy. Its objective is to strengthen relations with Southeast Asian countries and to support the development of India’s northeastern regions by improving infrastructure and transport accessibility.

Although many studies, both in Poland and internationally, have addressed specific dimensions of road transport development, there is a noticeable lack of integrated regional-level analyses combining infrastructure, enterprise activity, transport volumes, vehicle stock, and investment intensity. This research gap limits the ability to assess regional disparities comprehensively and hinders cross-country comparability. To address this, the present study applies the multi-criteria decision analysis method TOPSIS, which enables an overall assessment and ranking of voivodeships by their level of road transport development, based on the above-mentioned aspects of this development.

On the other hand, empirical results show that commercial banks can improve the credit rating model by including the relationship lending qualitative (soft) information of the borrower in the rating process, and that focus only on the hard financial information can be misleading (Dolezal et al., 2015).

3. Methods

The study used the TOPSIS technique, widely used to rank entities described by multiple criteria, including in research on transport systems (Koszela et al., 2020; Hajduk, 2022; Hamurcu, Eren, 2022; Poplawski et al., 2024). This method facilitates the assessment of how close each alternative is to a designated ideal and how far it is from a defined anti-ideal (Hwang, Yoon, 1981). It belongs to the family of MCDA/MCDM approaches² and is often applied to address practical decision-making challenges. Its outcome is a linear ranking of units, with the best-performing entity positioned closest to the hypothetical ideal and farthest from the worst-case alternative. The ideal solution is a notional construct exhibiting maximal values for stimulants and minimal ones for destimulants, whereas the anti-ideal reflects the opposite scenario (Ertman, 2011; Zalewski, 2012; Karim, Karmaker, 2016).

The TOPSIS method considers a set of k objects described by m variables, resulting in a data matrix X [$k \times m$] containing the values each object achieves for each variable. Additionally, the TOPSIS method requires an arbitrarily defined weight vector w [$1 \times m$] for the individual attributes³ (Zalewski, 2012). This allows for the differentiation of the relative importance of each variable in shaping the studied phenomenon.

² *Multiple-criteria decision analysis* (MCDA) and *Multiple-criteria decision making* (MCDM) represent a specialised area within operations research that concentrates on designing computational methods to assist in the subjective assessment of a limited number of decision options, each evaluated against a defined set of performance criteria (Karim, Karmaker, 2016).

³ In the study, all variables were arbitrarily assigned a weight of 1, assuming their comparable influence on shaping the level of road transport development.

The authors relied on a review of the literature and their own research experience to determine the variables affecting road transport development in Poland's voivodeships. To ensure comparability of variables between voivodeships, the characteristics were expressed as relative values—indicators. The analysis was conducted for 2010 and 2023, allowing for observing transport development changes across Polish regions.

In the initial phase of the research, following a formal review and content-based evaluation of indicators, a collection of 85 diagnostic measures was identified. Six of them were identified as destimulants and the remaining 79 as stimulants. The potential diagnostic variables covered the following components of road transport: transport enterprises, road infrastructure, means of transport, freight and passenger transport volumes, urban public transport, and road safety.

The analysis focused exclusively on variables exhibiting substantial variability and minimal mutual correlation. Consequently, in the second step, the pool of candidate indicators was narrowed using Hellwig's variability coefficients and the parametric classification approach (Hellwig, 1981; Bąk, 2017). The threshold for Pearson's linear correlation coefficient was set at 0.8 ($r^* = 0.8$), while the minimum acceptable level of variability was defined as 10% ($V = 0.1$). Based on these parameters, 60 indicators were excluded from further consideration.

To present the classification of voivodeships using a composite indicator calculated with the TOPSIS method, a final set of 25 measurable and available diagnostic variables was selected: X1 – gross value of fixed assets per capita (current recorded prices), X2 – share of investments in public roads in total national economy investment expenditures, X3 – density of district public roads, X4 – density of total hard-surface public roads, X5 – density of expressways, X6 – density of motorways, X7 – number of temporary bridges and flyovers, X8 – number of ferry crossings, X9 – number of petrol stations per 1000 motor vehicles, X10 – number of motorcycles per 1000 inhabitants, X11 – number of buses per 1000 inhabitants, X12 – number of trucks per 1000 inhabitants, X13 – number of mopeds per 1000 inhabitants, X14 – number of special trailers per 1000 inhabitants, X15 – number of special semi-trailers per 1000 inhabitants, X16 – share of outbound freight in the regional freight balance, X17 – share of inbound freight from internal regional transport in the regional freight balance, X18 – length of trolleybus lines in urban public transport, X19 – number of urban public transport buses per 1000 inhabitants, X20 – number of seats on urban public transport buses per 1000 inhabitants, X21 – number of seats on urban tram vehicles per 1000 inhabitants, X22 – number of buses used in international passenger transport per 1000 inhabitants, X23 – total domestic passenger transport per 1000 inhabitants, X24 – fatalities per 100 accidents, X25 – fatalities per 100,000 inhabitants.

The process of developing an object ranking based on the TOPSIS technique involved the subsequent steps (Ertman, 2011; Zalewski, 2012; Hajduk, Jelonek, 2021; Chakraborty, 2022):

1. Normalization of data from matrix $X [k \times m]$, using formula (1) to enable comparability between indicators:

$$Z_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^k X_{ij}^2}} \quad \text{for } i = 1, 2, \dots, k \text{ and } j = 1, 2, \dots, m \quad (1)$$

2. Inclusion of the weights attributed to each variable, as specified in formula (2):

$$v_{ij} = w_j * Z_{ij} \quad \text{for } i = 1, 2, \dots, k \text{ and } j = 1, 2, \dots, m \quad (2)$$

3. Establishing the specific values that variables take for both the ideal a^+ and anti-ideal a^- scenarios:

$$a^+ = [v_1^+, v_2^+, \dots, v_m^+] \quad (3)$$

$$a^- = [v_1^-, v_2^-, \dots, v_m^-] \quad (4)$$

where:

$$v_j^+ = \begin{cases} \max(v_{ij}), \text{ when attribute } j \text{ belong to the set of stimulants} \\ \min(v_{ij}), \text{ when attribute } j \text{ belongs to the set of destimulants} \end{cases}$$

$$v_j^- = \begin{cases} \min(v_{ij}), \text{ when attribute } j \text{ belongs to the set of stimulants} \\ \max(v_{ij}), \text{ when attribute } j \text{ belongs to the set of destimulants} \end{cases}$$

4. Calculation of the Euclidean distance between each object and both the ideal a^+ and anti-ideal a^- solutions, based on formulas (5) and (6):

$$d_i^+ = \sqrt{\sum_{j=1}^m (v_{ij} - v_j^+)^2} \quad \text{for } i = 1, 2, \dots, k \text{ and } j = 1, 2, \dots, m \quad (5)$$

$$d_i^- = \sqrt{\sum_{j=1}^m (v_{ij} - v_j^-)^2} \quad \text{for } i = 1, 2, \dots, k \text{ and } j = 1, 2, \dots, m \quad (6)$$

5. Determination of the synthetic ranking coefficient, which reflects how similar a given object is to the ideal solution, as defined by formula (7)

$$q_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad \text{for } i = 1, 2, \dots, k \quad (6)$$

The coefficient q_i takes values within the interval $[0,1]$, where a value of 1 corresponds to the ideal solution and 0 to the anti-ideal (Zalewski, 2012). The closer the value of q_i is to 1, the more similar the object is to the ideal reference point.

Calculating the composite indicator allows for a linear ranking of objects and facilitates their categorisation. Object typology is typically determined based on the arithmetic mean and standard deviation of the C coefficient, leading to the following classification (Ertman, 2011; Hajduk, Jelonek, 2021):

Group I – units with a very high indicator level ($q_i \geq \bar{q} + S_q$),

Group II – units with a high indicator level ($\bar{q} \leq q_i < \bar{q} + S_q$),

Group III – units with a low indicator level ($\bar{q} - S_q \leq q_i < \bar{q}$),

Group IV – units with a very low indicator level ($q_i < \bar{q} - S_q$),

where:

$\bar{q}$ – arithmetic mean of the composite indicator,

S_q – standard deviation of the composite indicator.

In this study, the defined groups represent the levels of road transport development observed among Polish voivodeships.

The application of the TOPSIS method, recognised for its flexibility and comparability across multi-criteria decision-making contexts, allows the study's results to be positioned within a broader international research framework. Given its widespread use in transport-related analyses globally, the approach adopted in this paper enables benchmarking and replication in other EU regions or countries facing similar infrastructure and development disparities.

4. Results and discussion

The composite indicator derived from the TOPSIS method enabled the classification of voivodeships into four categories reflecting road transport development levels: very high, high, low, and very low. The findings confirm significant regional variation in the advancement of road transport infrastructure (Table 1, Figures 1a and 1b). The gap between the leading voivodeship, Małopolskie, and the lowest-ranked voivodeship, Podlaskie, amounted to 0.305 in 2023. In the first year of the study (2010), it was 0.356 (between Małopolskie and Świętokrzyskie). This indicates a reduction in the gap between Polish regions regarding road transport development.

In 2010 and 2023, the regions with the highest levels of road transport development were the same three voivodeships: Małopolskie, Śląskie, and Wielkopolskie. The only difference was that in 2023, Śląskie and Małopolskie switched places compared to 2010. Nevertheless, Małopolskie consistently remained the ranking leader, achieving an indicator value of 0.555 in 2023 (an increase of 0.032 points compared to 2010). The development measure exceeded 0.5 in both analysed years (0.523 in 2010 and 0.555 in 2023), meaning that the indicator values for the top-ranked regions slightly approached the development benchmark.

Table 1.

TOPSIS-based composite measures of road transport development across voivodeships in 2010 and 2023

2010			2023		
Position in ranking	Voivodeship	Composite score	Position in ranking	Voivodeship	Composite score
Voivodeships characterised by the highest composite level of road transport development					
$q_i \geq 0.446$			$q_i \geq 0.480$		
1	Małopolskie	0.523	1	Małopolskie	0.555
2	Śląskie	0.507	2	Wielkopolskie	0.530
3	Wielkopolskie	0.428	3	Śląskie	0.515
Voivodeships showing a high level of development in road transport					
$0.346 \leq q_i < 0.446$			$0.379 \leq q_i < 0.480$		
4	Podkarpackie	0.412	4	Zachodniopomorskie	0.441
5	Dolnośląskie	0.408	5	Mazowieckie	0.426
6	Zachodniopomorskie	0.386	6	Podkarpackie	0.407
7	Mazowieckie	0.379	7	Lubuskie	0.407
8	Lubuskie	0.365	8	Łódzkie	0.399
			9	Kujawsko-pomorskie	0.398
Voivodeships exhibiting low levels of road transport advancement					
$0.246 \leq q_i < 0.346$			$0.278 \leq q_i < 0.379$		
9	Łódzkie	0.335	10	Podlaskie	0.341
10	Kujawsko-pomorskie	0.320	11	Dolnośląskie	0.329
11	Opolskie	0.309			
12	Pomorskie	0.295			
Voivodeships marked by very low performance in road transport development					
$q_i < 0.246$			$q_i < 0.278$		
13	Lubelskie	0.237	12	Opolskie	0.275
14	Warmińsko-mazurskie	0.232	13	Pomorskie	0.268
15	Świętokrzyskie	0.231	14	Lubelskie	0.261
16	Podlaskie	0.167	15	Warmińsko-mazurskie	0.256
			16	Świętokrzyskie	0.250

Source: Authors' calculations using data from the Central Statistical Office (Local Data Bank), including transport performance indicators and official road transport statistics for Poland in 2010 and 2023 (GUS, 2011, 2013, 2024a, 2024b, 2025).

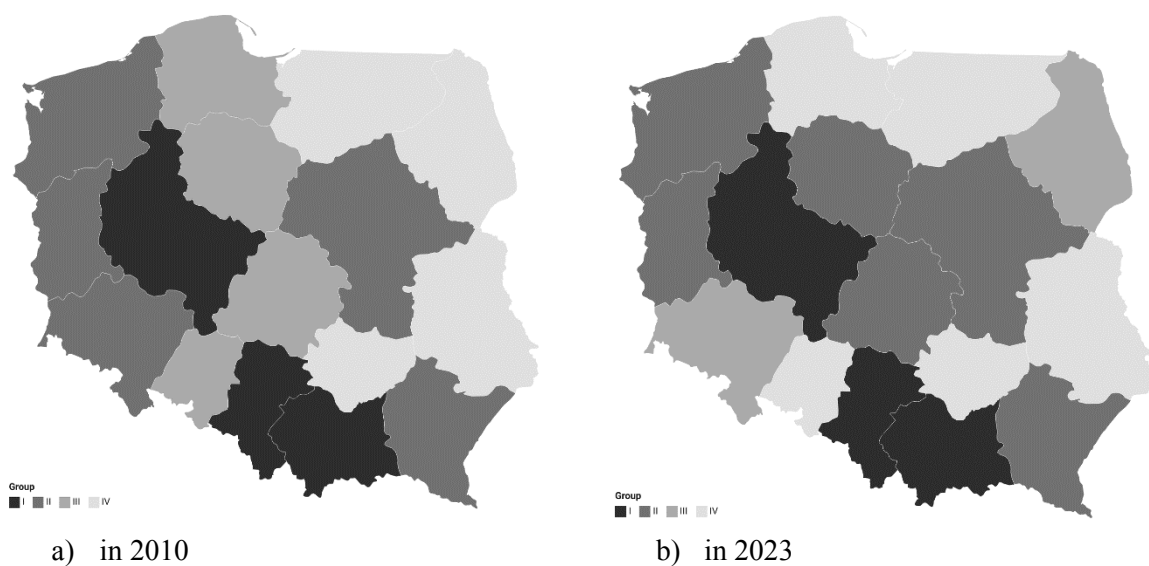


Figure 1. Spatial differentiation of the level of road transport development in Polish regions based on the TOPSIS method.

Source: authors' study based on data from Table 1.

Meanwhile, Śląskie voivodeship ranked third in 2023 with a TOPSIS indicator value of 0.515, which means it dropped from second to third position compared to 2010, despite an increase of 0.023 points. This indicates that other voivodeships also improved their ranking positions. Wielkopolskie voivodeship took second place in 2023 with an indicator value of 0.530 (an increase of 0.102 points). In 2010, the high position of Małopolskie voivodeship was influenced by several factors: it had the highest value for indicator X7 (temporary bridges and flyovers, 88 units), in ranked second for indicators X4 (density of total hard-surface, 155.8 km/km²) and X8 equal to that of Zachodniopomorskie voivodeship, third for X1 and X3, and fourth for X21. In 2023 (the second year of analysis), Małopolskie voivodeship again had the highest value for indicator X7, second place for X4 and X8, and third place for X3 and X21.

In 2010, the regions characterised by a high level of road transport development were Podkarpackie, Dolnośląskie, Zachodniopomorskie, Mazowieckie, and Lubuskie voivodeships. After fourteen years, the areas with a high level of development, now comprising six voivodeships, expanded to include Łódzkie and Kujawsko-Pomorskie. At the same time, the Dolnośląskie voivodeship fell into regions with low road transport development. Notably, the presence of Mazowieckie voivodeship in this group is surprising, as it has frequently ranked among the top positions in many rankings. Similarly, Zachodniopomorskie voivodeship, which has usually been placed at the lower end of rankings, significantly improved its standing in this study, becoming the leader of group II. This improvement was accompanied by an increase of 0.055 points in the TOPSIS indicator.

In 2010, only four voivodeships Łódzkie, Kujawsko-Pomorskie, Opolskie, and Pomorskie—were classified as having a low level of road transport development, while in 2023, this number had decreased to only two. The first two of these regions improved their position and moved to the group with a high level of development. In contrast, the last two voivodeships experienced a drop in ranking and were placed in the group with indicator values in the range of $0.278 \leq q_i < 0.379$. As a result, in 2023, this group included two voivodeships: Podlaskie, which advanced from group III (with an increase of 0.167 points in the composite indicator), and Dolnośląskie, which fell by six positions despite an increase of 0.079 points in the TOPSIS indicator. Podlaskie voivodeship recorded the highest values for variable X2 and a high ranking for indicator X15.

In 2010, four voivodeships – Lubelskie, Warmińsko-Mazurskie, Świętokrzyskie, and Podlaskie – were classified as having a synthetic TOPSIS index value below $q_i < 0.246$. Fourteen years later, in 2023, the category of regions characterised by very low performance in road transport development included five voivodeships: Opolskie (a decrease in q_i of 0.034 points), Pomorskie (a decrease in q_i of 0.027 points), Lubelskie (an increase in q_i of 0.024 points), Warmińsko-Mazurskie (a decrease in q_i of 0.024 points), and Świętokrzyskie (a decrease in q_i of 0.019 points).

The analysis indicates that in the years under study, road transport development inequalities occurred between regions and within groups. The distance between the leader of the ranking in 2010 (Małopolskie) and the region in last place (Podlaskie) was significant and amounted to 0.346; in the subsequent year of analysis, it was slightly smaller at 0.305 (between Małopolskie and Świętokrzyskie). Over the fourteen-year period, the gap between the highest and lowest values of the composite indicator among voivodeships demonstrating the most advanced stage of development narrowed – from 0.095 in 2010 to 0.040 in 2023. This indicates a narrowing of disparities within the first group of regions. In the third group, the within-group distance changed from 0.040 in 2010 to 0.012 in 2023. Twelve voivodeships recorded an increase in the synthetic TOPSIS indicator, while only four recorded a decrease. The highest increases were recorded in Podlaskie (by 0.174), Wielkopolskie (by 0.102), and Kujawsko-Pomorskie (by 0.078). The smallest decreases were observed in Podkarpackie (by 0.005), Śląskie (by 0.008), as well as Lubelskie and Warmińsko-Mazurskie (each by 0.024). The most significant improvement in ranking position occurred in Podlaskie (an increase of 6 places), followed by Zachodniopomorskie and Mazowieckie (a rise of 2 places). In contrast, Dolnośląskie recorded a drop of 6 places, and Podkarpackie a drop of 2 places. In the remaining voivodeships, changes amounted to a rise or fall of 1 place. In four voivodeships (Śląskie, Lubelskie, Warmińsko-Mazurskie and Świętokrzyskie), a discrepancy between absolute indicator values and relative ranking positions is observed. These regions improved their synthetic indicator scores, yet dropped in the ranking compared to other regions where road transport developed more dynamically.

The analysis outcomes confirmed the presence of considerable spatial variation in the level of road transport development among Polish voivodeships, accompanied by a visible narrowing of these differences between 2010 and 2023. The sustained strong position of Małopolskie, Śląskie, and Wielkopolskie voivodeships is consistent with previous studies, which indicate the importance of the regions' economic potential and earlier infrastructure investments in shaping transport accessibility (Cieślak, Rokicki, 2013; Karolewski, Roman, 2021).

The obtained results confirm the hypothesis of a strong relationship between the development of transport infrastructure and regional economic activity. The highest-ranked voivodeships were characterised by a more developed road network (variables X4, X6, X7) and an extensive fleet and passenger transport system (X11, X19, X23). This is consistent with the findings of Prus and Sikora (2021) and Rokicki et al. (2021), who emphasised the key role of transport infrastructure in stimulating regional economic growth.

The improvement in the position of Podlaskie voivodeship may indicate the effective use of investment resources and improvement in selected road transport components. This phenomenon aligns with the findings of international studies, which have emphasised that well-targeted investment activities can effectively reduce regional disparities in infrastructure and transport accessibility (Masárová, Ivanová, 2016; Elburz, Cubukcu, 2021).

At the same time, the reclassification of Dolnośląskie voivodeship from the category of regions with a high level of road transport development to one ranked lower—despite a rise in the synthetic TOPSIS score—emphasises the complex interplay between infrastructure quality, population characteristics, and investment dynamics. This observation aligns with the findings of Li et al. (2018) and Agnihotri and Tripathi (2023), who noted that infrastructure's contribution to regional development depends not solely on network expansion, but also on how effectively it addresses the specific needs of local communities.

The regional disparities in motorisation, previously analysed by Kudlak, Kisiała, and Kołsut (2023), continue to serve as an important background for understanding shifts within Poland's road transport system. In this study, the indicator reflecting the number of passenger vehicles per 1000 residents was excluded at the stage of variable selection due to its limited variability (coefficient of variation: 6.7%), and thus this factor was not explicitly incorporated in the analysis. However, earlier findings by Czernicki and Wacek (2019) suggest that in areas with restricted availability of public transport, there has been a tendency toward increased reliance on private vehicles, potentially exacerbating inequalities in transport access between central and peripheral zones.

In summary, the study confirmed earlier research findings regarding the differentiation of road transport development in Poland. It demonstrated that the dynamics of these changes depend on investment strategies, demographic conditions, and the implemented transport policies at the regional level. The study contributes significantly to the literature by integrating various dimensions of road transport development and providing a classification of voivodeships based on a multi-criteria comparative analysis.

5. Conclusions

A well-functioning regional economy depends on the availability of appropriate infrastructure, with road transport playing a particularly crucial role as a platform for supporting socio-economic progress. As part of territorial infrastructure, the road transport sector represents a significant determinant of regional socio-economic growth. It also plays a vital role in fostering the development of local communities, both socially and economically. Consequently, analysing spatial disparities in road transport development across Polish voivodeships offers valuable insights for formulating national transport strategies and guiding regional policy-making. The evaluation of road transport development allows the formulation of the following conclusions:

- The level of road transport development, as measured by the synthetic TOPSIS indicator, shows differentiation among Polish regions, although it cannot be described as highly unequal. The composite indicator for the best-performing region in both analysed years was relatively high, yet still below the benchmark level of development. The ranking leader in the analysed period was Małopolskie voivodeship, with an indicator value of 0.523 in the first year of the study (0.555 in 2023). Over the fourteen-year period, the value range declined relative to the baseline year, reaching 0.356 and 0.305, respectively. This reflects the persistence of regional disparities in road transport advancement.
- In 2010, half of the voivodeships were classified into the category with the highest level of road transport development. By 2023, this number had increased to nine. The distribution of voivodeships across the groups remained relatively stable in both years of analysis. Małopolskie, Śląskie, and Wielkopolskie consistently ranked among the regions with the highest level of road transport development in both 2010 and 2023. In contrast, Lubelskie, Warmińsko-Mazurskie, Świętokrzyskie, and Podlaskie occupied the lowest positions in 2010, while in 2023, the five lowest-ranked voivodeships were Opolskie, Pomorskie, Lubelskie, Warmińsko-Mazurskie, and Świętokrzyskie.
- Road transport development levels across Polish voivodeships continue to show considerable variation. The composite TOPSIS index, which reflects the extent of road transport advancement, confirmed the gap between Małopolskie and Podlaskie voivodeships, where in 2010 the ratio stood at 3:1. Fourteen years later, this disparity narrowed to 2:1 – between Małopolskie and Świętokrzyskie.

The empirical findings presented in this study are highly relevant to regional development, as they offer decision-makers insight into road transport assets that may be applied in policy-making at both national and regional levels. This knowledge base can inform the allocation of EU funding, including initiatives aimed at improving regional transport infrastructure. The anticipated outcomes of investments in road transport – expressed through enhanced development potential and increased regional investment appeal – should ultimately contribute to better living standards in local communities and the economic advancement of territorial entities.

This article delivers an empirical analysis of regional variation in road transport development across Poland. The adopted timeframe and the outcomes of the study constitute its main strengths and may prove useful in shaping policies and programmes aimed at improving road transport systems. Data availability, particularly its consistency over the adopted time frame, constituted a study limitation. Future studies could examine how Poland's level of road transport development compares with that of other EU countries. There is also room for more focused research on the influence of road transport on the socio-economic performance of Polish regions, as it remains a fundamental driver of their development.

Although this study is focused on Polish voivodeships, its findings may be relevant for other EU countries facing regional disparities in transport infrastructure. The analytical framework used here could serve as a useful reference for policymakers aiming to evaluate and prioritise regional transport investments in line with EU cohesion policy objectives.

In this regard, the presented methodology and results may support decision-making at both national and EU levels, particularly in the programming of investment strategies under cohesion policy and the European Structural and Investment Funds (ESIF). The transparency of the methodology used, in conjunction with the availability of comparable transport indicators within EU Member States, means that this approach can be adapted for cross-country comparisons. However, it should be noted that not all indicators used in this study may have direct counterparts in standardised EU transport metrics, which could limit the scope of cross-country comparability.

References

1. Agnihotri, J., Tripathi, R. (2023). Transportation, Concept, and Its Impact on Economic Development: A Review from the Perspective of the Mountainous Region. *International Journal on Recent and Innovation Trends in Computing and Communication*, 11(11), pp. 13-23. doi:10.17762/ijritcc.v11i11.9070
2. Antonescu, D., Florescu, I.C. (2024). The Dynamics of Regional Inequalities in Romania. Comparative Analysis between the major Crises – Financial and Sanitary. *Central European Journal of Geography and Sustainable Development*, 6(1), pp. 5-29. doi:10.47246/cejgsd.2024.6.1.1
3. Bąk, A. (2017). Statystyczne metody doboru zmiennych w porządkowaniu liniowym. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, 468, pp. 29-37.
4. Bekisz, A., Kruszyński, M. (2021). Analysis of the Diversity of Regional Development of Road Transport Infrastructure in Poland. *European Research Studies Journal*, XXIV, Iss. 2B, pp. 712-723. doi:10.35808/ersj/2260
5. Del Bo, C., Del Massimo, F. (2008). *Infrastructure and Growth in the European Union: an Empirical Analysis at the Regional Level in a Spatial Framework*, 37. Milano. Available at: <https://www.researchgate.net/publication/46466379>
6. Burghardt, K. et al. (2022). Road network evolution in the urban and rural United States since 1900. *Computers, Environment and Urban Systems*, 95(April), p. 101803. doi:10.1016/j.compenvurbsys.2022.101803
7. Butkus, M., Mačiulytė-Šniukienė, A., Matuzevičiūtė, K. (2023). Transport Infrastructure Investments as a Factor of Economic Growth of European Union Countries. *TalTech Journal of European Studies*, 13(1), pp. 150-176. doi:10.2478/bjes-2023-0008

8. Chakraborty, S. (2022). TOPSIS and Modified TOPSIS: A comparative analysis. *Decision Analytics Journal*, 2(September 2021), pp. 1-7. doi:10.1016/j.dajour.2021.100021
9. Cieřlik, A., Rokicki, B. (2013). Rola sieci transportowej w rozwoju polskich regionów: zastosowanie modelu potencjału ekonomicznego. *Acta Universitatis Nicolai Copernici Oeconomia*, 44(1), p. 113. doi:10.12775/aunc_ekon.v44i1.2205
10. Cigu, E. et al. (2019). Transport infrastructure development, public performance and long-run economic growth: A case study for the Eu-28 Countries. *Sustainability (Switzerland)*, 11(1), pp. 1-22. doi:10.3390/su11010067
11. Czernicki, Ł., Wacek, P. (2019). *Transport inkluzyny – rola polityki transportowej w kształtowaniu zrównoważonego rozwoju kraju*. Warszawa. Available at: <https://pie.net.pl/wp-content/uploads/2019/05/PIE-Transport.pdf>
12. Ejdyś, S. (2017). Spójny i zrównoważony system transportowy Warmii i Mazur. *Optimum. Studia Ekonomiczne*, 4(88), pp. 199-212. doi:10.15290/ose.2017.04.88.15
13. Elburz, Z., Cubukcu, K.M. (2021). Spatial effects of transport infrastructure on regional growth: the case of Turkey. *Spatial Information Research*, 29(1), pp. 19-30. doi:10.1007/s41324-020-00332-y
14. Ertman, A. (2011). Zróżnicowanie elastyczności rynków pracy w wybranych krajach europejskich oraz USA w świetle metody TOPSIS. *Oeconomia Copernicana*, 3(3), pp. 43-64.
15. Falkowski, M., Pytel, M. (2013). Typology of Basic Academic Notions Related to the Transport System. *European Journal of Geopolitics*, 1, pp. 37-60.
16. Ferrarini, F., Muzzioli, S., De Baets, B. (2024). A TOPSIS analysis of regional competitiveness at European level. *Competitiveness Review: An International Business Journal*, 34(7), pp. 52-72. doi:10.1108/CR-01-2024-0005
17. Gajewski, R. (2024). Main Directions of Changes in Road Transport of Goods in Poland. *Annales Universitatis Mariae Curie-Skłodowska, sectio H – Oeconomia*, 58(5), pp. 7-20. doi:10.17951/h.2024.58.5.7-20
18. Gaus, D., Link, H. (2020). Economic Effects of Transportation Infrastructure Quantity and Quality: A Study of German Counties. *DIW Discussion Papers*, 1848. Berlin. doi:10.2139/ssrn.3545188
19. GUS (2011). *Transport – wyniki działalności w 2010 r.* Warszawa.
20. GUS (2013). *Transport drogowy w Polsce w latach 2010 i 2011*. Warszawa.
21. GUS (2024a). *Transport – wyniki działalności w 2023 r.* Warszawa/Szczecin.
22. GUS (2024b). *Transport drogowy w Polsce w latach 2022 i 2023*. Warszawa/Szczecin.
23. GUS (2025). *Bank Danych Lokalnych*. Warszawa: GUS. Available at: <https://bdl.stat.gov.pl/BDL/start>, 3 April 2025.
24. Hajduk, S. (2022). Multi-Criteria Analysis in the Decision-Making Approach for the Linear Ordering of Urban Transport Based on TOPSIS Technique. *Energies*, 15(274), pp. 1-30. doi:<https://doi.org/10.3390/en15010274>

25. Hajduk, S., Jelonek, D. (2021). A Decision-Making Approach Based on TOPSIS Method for Ranking Smart Cities in the Context of Urban Energy. *Energies*, 14(9), pp. 1-23. doi:10.3390/en14092691
26. Hamurcu, M., Eren, T. (2022). Applications of the Moora and Topsis Methods for Decision of Electric Vehicles in Public Transportation Technology. *Transport*, 37(4), pp. 251-263. doi:10.3846/transport.2022.17783
27. Hellwig, Z. (1981). Wielowymiarowa analiza porównawcza i jej zastosowanie w badaniach wielocechowych obiektów gospodarczych. In: W. Welfe (ed.), *Metody i modele ekonomiczno-matematyczne w doskonaleniu zarządzania gospodarką socjalistyczną*. Warszawa: PWE, pp. 46-68.
28. Hwang, C.-L., Yoon, K. (1981). *Multiple Attribute Decision Making*. M. Beckmann, H.P. Künzi (ed.). Berlin/Heidelberg/New York: Springer-Verlag (Lecture Notes In Economics and Mathematical Systems). doi:10.1007/978-3-642-48318-9 e-ISBN-13
29. Jain, J., Sesidhar, S.V., Gupta, N. (2023). Influence of Regional Transport Accessibility on Development of Settlements: a Case of Visakhapatnam Region. *Planning Malaysia: Journal of the Malaysian Institute of Planners*, 21(2), pp. 104-116. doi:10.21837/pm.v21i26.1262
30. Janic, M., Reggiani, A. (2001). Integrated transport systems in the European Union: An overview of some recent developments. *Transport Reviews*, 21(4), pp. 469-497. doi:10.1080/01441640110042147
31. Karim, R., Karmaker, C.L. (2016). Machine Selection by AHP and TOPSIS Methods. *American Journal of Industrial Engineering*, Vol. 4(1), pp. 7-13. doi:10.12691/ajie-4-1-2
32. Karolewski, M., Roman, M. (2021). Przestrzenne zróżnicowanie rozwoju infrastruktury liniowej transportu drogowego w Polsce w latach 2004-2019. *Ekonomika i Organizacja Logistyki*, 6(1), pp. 39-49. doi:10.22630/eiol.2021.6.1.4
33. Koner, J., Bhadury, B., Purandare, A. (2022). Road Infrastructure Development and Economic Growth of North-Eastern States in India: A Revisit. *NICMAR-Journal of Construction Management*, XXXVII(4), pp. 85-90.
34. Koszela, G. et al. (2020). A comparison of logistics infrastructure development level of European Union countries using Topsis and Vikor methods. *Economics and Organization of Logistics*, 5(1), pp. 15-27. doi:10.22630/eiol.2020.5.1.2
35. Koźlak, A. (2007). *Ekonomika transportu. Teoria i praktyka gospodarcza*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
36. Kozubek, P.R. (2019). Strategia rozwoju zrównoważonego a rozwój infrastruktury transportu w Polsce w latach 1989-2018. In: Kotowska-Jelonek, M. (ed.), *Przemiany społeczno-gospodarcze w Polsce w latach 1989-2018. Wybrane sektory, mechanizmy, instrumenty wsparcia* (pp. 11-39). Kielce: Wydawnictwo Politechniki Świętokrzyskiej.

37. Kudłak, R., Kisiała, W., Kołsut, B. (2023). Determinanty posiadania samochodu w Polsce: wyniki modelowania w ujęciu przestrzennym w latach 2005 i 2019. *Ekonomista*, 2, pp. 152-173. doi:10.52335/ekon/166246
38. Kurowski, J. (2017). System transportowy i jego uwarunkowania – aspekty gospodarczo-obronne. *Zeszyty Naukowe Akademii Sztuki Wojennej*, 107(2), pp. 98-115. doi:10.5604/01.3001.0010.7972
39. Li, H., Liu, Y., Peng, K. (2018). Characterizing the relationship between road infrastructure and local economy using structural equation modeling. *Transport Policy*, 61(1), pp. 17-25. doi:10.1016/j.tranpol.2017.10.002
40. Li, S. et al. (2024). The Evolution and Economic and Social Effects of the Spatial and Temporal Pattern of Transport Superiority Degree in Southern Xinjiang, China. *Land*, 13(216), pp. 1-20.
41. Luty, L., Ziolo, M. (2015). Zróżnicowanie infrastruktury drogowej w Polsce w ujęciu przestrzenny w 2013 roku. *Metody ilościowe w badaniach ekonomicznych*, XVI(3), pp. 258-268.
42. Masárová, J., Ivanová, E. (2016). Road infrastructure in the regions of the Slovak Republic and Poland. *Bulletin of Geography. Socio-economic Series*, 33, pp. 79-90. doi:10.1515/bog-2016-0026
43. Nandy, S.N. (2014). Road Infrastructure in Economically Underdeveloped North-east India: A District Level Study. *Journal of Infrastructure Development*, 6(2), pp. 1-14. doi:10.1177/0974930614564648
44. Nogués, S., González-González, E. (2022). Are current road investments exacerbating spatial inequalities inside European peripheral regions? *European Planning Studies*, 30(10), pp. 1845-1871. doi:10.1080/09654313.2021.1934407
45. Pokharel, R., Bertolini, L., te Brömmelstroet, M. (2023). How does transportation facilitate regional economic development? A heuristic mapping of the literature. *Transportation Research Interdisciplinary Perspectives*, 19, pp. 1-13. doi:10.1016/j.trip.2023.100817
46. Poliak, M. et al. (2023). Identification of the Impact of Transport Performance on the Economy of Particular Area. *LOGI - Scientific Journal on Transport and Logistics*, 14(1), pp. 192-202. doi:10.2478/logi-2023-0018
47. Poplawski, L. et al. (2024). Spatial differentiation of Poland's voivodeship in the context of linear infrastructure development in 2011-2021. *Acta Logistica*, 11(4), pp. 697-707. doi:10.22306/al.v11i4.569
48. Prus, P., Sikora, M. (2021). The impact of transport infrastructure on the sustainable development of the region—case study. *Agriculture*, 11(279), pp. 1-15. doi:10.3390/agriculture11040279
49. Rokicki, B. et al. (2021). Accessibility in the regional CGE framework: the effects of major transport infrastructure investments in Poland. *Transportation*, 48(2), pp. 747-772. doi:10.1007/s11116-019-10076-w

50. Wiśniewski, S. (2015). Zmiany dostępności miast województwa łódzkiego w transporcie indywidualnym w latach 2013-2015. *Przegląd Geograficzny*, 87(2), pp. 321-342. doi:<http://dx.doi.org/10.7163/PrzG.2015.2.6>
51. Wornalkiewicz, W., Kaplunovska, A., Padchenko, O. (2021). Transport infrastructure as a factor of the EU countries' economic development. *Ukrainian Journal of Applied Economics*, 6(2), pp. 137-146.
52. Yang, L. et al. (2022). Transportation Interrelation Embedded in Regional Development: The Characteristics and Drivers of Road Transportation Interrelation in Guangdong Province, China. *Sustainability*, 14(5925), pp. 1-18. doi:10.3390/su14105925
53. Zalewski, W. (2012). Zastosowanie metody TOPSIS do oceny kondycji finansowej spółek dystrybucyjnych energii elektrycznej. *Economics and Management*, 4, pp. 137-145.