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Spatial differentiation of Poland's voivodeship in the context of linear infrastructure development in 2011-2021

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Abstract: The development of linear infrastructure is important for the development of logistics, for the economic development of regions. The is at the same time spatially differentiated between regions. The regions are strongly developing their linear infrastructure in order to reduce the disparities in the development of facilities and roads. The aim of the study was to diagnose the condition of linear infrastructure and to indicate its spatial changes in the years 2011-2021 in Poland. The were used to build a synthetic measure using the Technique for Order Preference by Similarity to an Ideal Solution method. The synthetic measure of linear infrastructure ranged from 0.01 (warmińsko-mazurskie) to 0.60 (śląskie) in 2010 and 0.31 (świętokrzyskie, podlaskie) to 0.56 (śląskie, małopolskie) in 2021. A higher value of synthetic measure of linear infrastructure indicates a better position and higher competitiveness of the voivodeship within the research area. The provinces well equipped with linear infrastructure include the provinces of śląskie, dolnośląskie, małopolskie. The provinces where there is an improvement, and road connections are developing, include podlaskie, świętokrzyskie. They are not counted among the highly developed economically and do not make the best use of the opportunities offered by a developed road network. Action taken in this aspect must be based on analyses to facilitate comparisons and on current information necessary for effective action.

1 Introduction

The nation's transportation infrastructure is essential to its economic growth. Is a crucial sign of its economic expansion. Roads, highways, and railroads are examples of linear infrastructure. They provide serious hazards to the local ecosystem and biodiversity, but they can also have major positive social and economic effects. For linear infrastructure, a spatial planning tool that balances the costs and advantages of environmental and socioeconomic factors is required. A variety of infrastructures are necessary for the growth and welfare of human society. Linear infrastructures have created significant ecological and environmental issues in addition to their enormous economic benefits (Wu, Li 2022) [1].

Infrastructure plays an important role in promoting the socio-economic development of a region. In particular, the provision of transport infrastructure is important for agri-food supply chains, which have some specific characteristics that contribute to the complexity of external logistics. Transport infrastructure has an impact on green and sustainable development, on economic growth due to the investment during the construction period and the possible positive externalities after construction. More energy is used and, consequently, more CO2 is released during the building of transportation infrastructure, which has an adverse effect on the environment. Because it facilitates the movement of people and the trade of goods across space. The transport infrastructure plays a role in the growth and development of an area. In addition to causing landscape fragmentation, the construction of linear infrastructures has a variety of negative effects on biodiversity and natural habitats (Tan, Pan, Xu, He, 2022) [2].

The European Union (EU) has paid particular attention to the development of infrastructure, especially transportation, considering it a key element in ensuring territorial cohesion. Investing in transportation is key to sustainable development, enabling the free movement of people, goods and services, which translates into economic development and cooperation between countries. As part of its cohesion policy, the EU invests in the construction and modernization of road, rail, sea and air networks, aiming to close the gap in access to modern modes of transportation. Such policies aim not only to improve mobility, but also to integrate peripheral areas, which in the past were less developed and had difficult access to key markets [3]. The road system plays a key role in both maintaining the health of the economy and generating social benefits. With an ever-increasing awareness of climate change and sustainability, transportation infrastructure researchers, engineers, and practitioners are pursuing innovations to conserve natural resources and reduce energy consumption and emissions. Roads are the backbone of transportation, which drives trade, tourism, and industry, which in turn drives economic growth. As a result, a well-developed road infrastructure promotes economic stability and attracts investment. The road system not only supports the economy but also has a tremendous impact on improving the quality of life of society, reducing geographic isolation, improving access to services, and integrating communities [4]. Differences in the efficiency of infrastructure and quality of logistics systems in different countries can be identified as the source of several problems in the global supply chain, such as lack of connectivity between countries, congestion, high costs, delays in shipment flows and the associated increase in logistics costs [5].

The aim of the research was to assess the spatial disproportion of linear infrastructure at the level of voivodeships in Poland. A voivodeship in Poland is a territorial subdivision that is an administrative part of the country, which is responsible for carrying out public tasks. The availability of data from Statistics Poland played a key role in their selection. The research process sought to identify the essence of linear infrastructure and areas affected by polarisation in the provincial economic system in 2011-2021. The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method was used to build a synthetic measure. The analysis was performed for the years 2011-2021, and the results were presented for extreme years. This made it possible to indicate the dynamic aspects of the phenomena studied and to control deviations in the phenomenon associated with changes in, for example, the economic climate of the province. Implementation of the objective required answers to the research questions, i.e. What is linear infrastructure and what are its determinants? Is there territorial cohesion in terms of linear infrastructure? What is the strength of the interactions between the linear infrastructure diagnostic variables? To what extent have spatial disparities in linear infrastructure been bridged?

2 Literature review

Infrastructure systems are interconnected and influence each other. A better understanding of these interdependencies supports urban and provincial efforts. Recognizing these interdependencies allows one to see patterns that can help bring about changes in urban and provincial infrastructure systems, preventing unexpected consequences and eliminating systemic blockages. Effectively sorting out the reciprocal mechanisms between infrastructure systems can enhance the understanding of transition processes in the context of sustainable development. Infrastructure systems are part of broader socio-technical systems that produce, process and distribute specialized services, materials and resources, thereby supporting the well-being of citizens and the proper functioning of cities. One of the key functions of social infrastructure is to provide basic urban services, such as the provision of energy, water, heat, transportation and sanitation, which meet social needs and contribute to the quality of life of residents [6].

Social institutions influence the formation of infrastructure systems through political action, lobbying, coalition building, and the establishment of social norms, customs, and culture. Institutions and infrastructure systems develop simultaneously, adapting to and influencing the changing needs of society. Spatial interdependence refers to the geographic proximity and common location of different infrastructure systems, such as the sharing of networks, infrastructure elements, and space. Functional interdependencies, on the other hand, arise when different infrastructure systems play complementary or competing roles, which affects their mutual functionality. These interdependencies result from the exchange of material resources and information, as well as from complementary or competing functions [7].

Transportation infrastructure is a key component of a well-functioning economy, playing a vital role in its economic and social development. Transportation brings numerous benefits to society, providing access to education, jobs, goods, services, as well as enabling leisure and promoting physical activity in daily life. The development of transportation infrastructure is considered an essential foundation for economic growth, as it directly supports production and economic activity. Investment in transportation affects economic growth by increasing the efficiency of labor and capital, reducing costs through improved transportation efficiency, accelerating structural change in regions, including the industrial sector, and modifying aggregate market demand [8].

In neoclassical economic growth theory, the development of transportation infrastructure combines technological and political factors to create a residual period of technological progress. The theory of endogenous economic growth suggests that the externalities of infrastructure investment are the primary source of long-term economic growth. The development of transportation infrastructure should be viewed as the physical capital of the region [9]. Governments, non-governmental organizations, and local communities are striving for sustainable development, which underpins activities at all levels of infrastructure management and development. In the context of transportation infrastructure construction, a key goal is to minimize the negative impact that construction materials, construction processes, and related activities have by reducing emissions, natural resource consumption, and environmental degradation. Sustainable development of transportation infrastructure focuses on balancing economic, social, and environmental needs to ensure long-term efficiency and minimize side effects on future generations [10].

The development and implementation of transportation infrastructure has a significant impact on the location decisions of businesses and households, as it improves accessibility to various markets, services and resources. This makes it easier for businesses to reach new customers and suppliers. For households, better transportation infrastructure provides easier access to jobs, education, health care and other services, which improves quality of life. Increasing accessibility and improving transportation can lead to increased traffic congestion, resulting in more traffic jams and longer travel times. Therefore, developing transportation infrastructure requires balancing the benefits of accessibility and efficiency with social and environmental costs [11]. A developed transportation infrastructure is a key determinant of regional advantages, as it reduces transportation costs, which encourages the development of various industries and sectors. Good transportation infrastructure contributes to the growth of industrial agglomerations, as it enables companies to concentrate in one region, which generates economies of scale and improves competitiveness [12]. The development of transportation infrastructure can reduce trade costs, narrowing the price gap and increasing inter-regional trade flows, leading to an improved trade environment, better market integration and an increase in gross domestic product (GDP) per capita [13]. Accessibility provided by transportation infrastructure helps people secure jobs, gives access to a variety of services, and allows businesses to interact with customers and manufacturers [14]. Transportation infrastructure is characterized by its durability, high construction and maintenance costs, long construction and use periods, and linear or point-to-point nature. Despite its many benefits, its development is associated with serious environmental consequences, including CO2 emissions from fossil fuels. Improving transportation infrastructure is key to allocating resources efficiently, creating a favorable business environment and providing higher returns on investment. In addition, government spending on transportation increases economic competitiveness, promotes trade, tourism, foreign investment and job creation [15].

The development of transportation infrastructure in cities should include not only automobile transportation, but also the development of public transport systems, pedestrian and bicycle paths, which positively affects the quality of life of residents. These investments must take into account measures to combat climate change, promoting low-carbon modes of transportation and investments in green infrastructure. The relationship between green infrastructure and transportation infrastructure is complex and dynamic, and their integration is key to achieving the goals of improving quality of life, reducing emissions and achieving social and economic sustainability.

Green infrastructure can mitigate problems associated with urbanization, support biodiversity, improve citizens' health, and increase resilience to climate change. The use of green infrastructure depends on financial resources and the urban environment, making it more accessible to wealthier neighborhoods. Economic barriers, such as entrance fees and transportation costs, can limit access to green spaces, so eliminating these obstacles is key to promoting social equity and inclusive access. Understanding inequalities in access to green infrastructure requires taking into account individual and neighborhood factors, the impact of which is still not fully understood [16].

Urbanization and growing urban populations are challenging existing transportation networks, requiring investment in new solutions and adaptation of current systems to meet the needs of modern agglomerations. It is crucial to ensure equal access to public transportation and infrastructure for all segments of society, especially the less affluent, in order to promote sustainable development. Transportation is a basic need that affects residents' independence, autonomy and quality of life [17].

3 Methodology

The process of constructing a synthetic measure using the TOPSIS method involves the following steps (Hajduk, Jelonek, 2021) [18]: (1) selection and verification of diagnostic variables (both substantive and statistical); (2) normalization variables and identification of stimulants and destimulants; (3) aggregation of the synthetic measure of linear infrastructure using the TOPSIS method; (4) ranking of voivodeships based on the synthetic measure of linear infrastructure; and (5), (6) interpretation of the results in relation to the studied entities.

To create a synthetic measure, diagnostic variables were chosen based on their substantive relevance, adequate coefficient of variation, and low correlation with other variables [19-20]. Table 1 presents the selected variables, which were gathered across the voivodeships of Poland.

Table 1 Diagnostic variables used in the analysis of linear infrastructure of voivodships in Poland

X1	Expenses Total transport and communications	pln/per capita	Stymulant
X2	Expenses - voivodship public roads	pln/per capita	Stymulant
X3	Roads for bicycles	km/100km2	Stymulant
X4	Total public roads	km/100km2	Stymulant
X5	Expressways and highways	km/100km2	Stymulant
X6	total bridges and viaducts	sz/100km2	Stymulant
X7	total railroads	km/100km2	Stymulant

A matrix of observations, denoted as X_{ij}, is used to represent the set of diagnostic variables:

$$X_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

where: $X_{ij} \in R$ - denotes the values of the i-th test object relative to the j-th diagnostic variable, i - object number (i = 1, 2, ..., n), j - variable number (j = 1, 2, ..., m).

The zeroed unitarization method was applied to normalize the diagnostic variables, scaling all values to the interval [0,1]. The variables are normalized according to the specified formulas [21]:

$$Z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ when } x_i \in S, \quad (2)$$

$$Z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ when } x_i \in D, \quad (3)$$

where: S-stimulant, D-destimulant; $\max_{xij}$ - the maximum value of the j-th variable, $\min_{xij}$ - the minimum value of the j-th variable, x_{ij} – denotes the value of the j-th variable for the i-th object [22], Z_{ij} normalization value of the j-th variable for the i-th object [23].

The unitization process produces a value matrix represented by the function Z_{ij}, which is expressed as follows:

$$Z_{ij} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix}, \quad (4).$$

The following formulas were used to compute the voivodeship's Euclidean distances from the pattern and anti-pattern:

(a) the distances of objects from the pattern:

$$d_i^+ = \sqrt{\frac{1}{n}\sum_{j=1}^{m}\left(z_{ij} - z_j^+\right)^2} \quad (5)$$

(b) the distance of objects from the anti-pattern:

$$d_i^- = \sqrt{\frac{1}{n}\sum_{j=1}^{m}\left(z_{ij} - z_j^-\right)^2} \quad (6)$$

where: n- denotes the number of variables building a pattern or anti-pattern, z_{ij} - denotes the normalized value of the j-th characteristic for the unit under study (or the normalized value of the j-th variable i-th object), z_j^+ / z_j^- - denotes a pattern or anti-pattern object [24].

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method was used to determine the synthetic measure for each province according to the formula (7):

$$q_{i\,(synthetic\ measure\ of\ linear\ infrastructure)} = \frac{d_i^-}{d_i^- + d_i^+}, gdzie\ 0 \le q_i \le 1, i = 1, 2, \ldots, n; \quad (7)$$

where: $q_i \in [0; 1]$; d_i^- - denotes the distance of the object from the anti-pattern (from 0), d_i^+ - denotes the distance of the object from the pattern (from 1). A higher value of the measure indicates the better situation of an individual in the studied area [25].

Based on the mean ($\bar{x}$) and standard deviation (Sd), four groups were found ordering the synthetic measure's values, according to the formula (8):

Group I (highest level)	$S(\bar{x})+S(s) \le q_i$	(8)
Group II (high level)	$S(\bar{x}) \le q_i < S(\bar{x})+S(s)$	
Group III (medium level)	$S(\bar{x})-S(s) \le q_i < S(\bar{x})$	
Group IV (low level)	$q_i < S(\bar{x})-S(s)$	

In Statistica software, bag plots, Gini coefficient, maps of spatial differentiation of provinces according to the synthetic measure, Pearson's linear correlation coefficients, Sperman's rank, gamma, and Kendall's tau were created.

4 Results and discussion

As society progresses and international relations become more interconnected, the role of transport infrastructure as a driver of economic and social development is becoming increasingly significant. The synthetic measure of linear infrastructure ranged from 0.01 (Warmińsko-Mazurskie) to 0.60 (Śląskie) in 2010, and from 0.31 (Świętokrzyskie, Podlaskie) to 0.56 (Śląskie, Małopolskie) in 2021. A higher value of the synthetic measure (q) indicates a better position and greater competitiveness of the voivodeship within the analyzed region (Table 2). These variations highlight the disparities in the development of linear infrastructure across Poland's regions. The differences in the synthetic measure reflect not only the level of infrastructure development but also the varying capacities of these regions to support economic growth and improve accessibility. It provides valuable insight into the evolving patterns of regional development and competitiveness.

Table 2 Groups of synthetic measure of the attractiveness of linear infrastructure of voivodships in Poland in 2011 and 2021

gr	voivodeship	synthetic measure in 2011	voivodeship	synthetic measure in 2021
I	Śląskie	0.60	Małopolskie	0.56
	Małopolskie	0.42	Śląskie	0.56
	Dolnośląskie	0.39	Dolnośląskie	0.49
II	Opolskie	0.29	Łódzkie	0.41
	Wielkopolskie	0.25	Kujawsko-pomorskie	0.41
			Wielkopolskie	0.40
III	Kujawsko-Pomorskie	0.23	Mazowieckie	0.39
	Świętokrzyskie	0.23	Lubelskie	0.38
	Mazowieckie	0.21	Warmińsko-mazurskie	0.36
	Łódzkie	0.21	Zachodniopomorskie	0.36
	Lubuskie	0.20	Pomorskie	0.36
	Pomorskie	0.20	Lubuskie	0.34
	Zachodniopomorskie	0.18	Opolskie	0.34
	Podkarpackie	0.18	Podkarpackie	0.33
	Lubelskie	0.17		
	Podlaskie	0.13		
IV	Warmińsko-Mazurskie	0.07	Podlaskie	0.31
			Świętokrzyskie	0.31

In Poland, there is significant regional variation in key elements of transport infrastructure, particularly in the density of motorways, expressways, and operational railways. In 2019, the density of municipal and district hard-surfaced roads in Poland reached 82.6 km per 100 km², marking an increase of 25% compared to 2005, when the density was 66.2 km per 100 km². This indicates a considerable improvement in the accessibility of local areas across the country in recent years. Such developments should be seen as highly positive, as they enhance opportunities for further regional growth and better connectivity within Poland [26]. The development of road infrastructure in Poland is a necessity and guarantees great benefits for society. Developed road infrastructure strengthens the economic, spatial and social cohesion of the country and its regions, provides opportunities to save on storage and transport costs, facilitates the sale of goods and services outside local markets, enables the movement of workers to more efficient and attractive regions, and increases the level of mobility of society [27].

Table 3 Descriptive statistics of diagnostic variables and synthetic measures of attractiveness of linear infrastructure of voivodeships in Poland in 2011 and 2021

	Average	Minimum	Maximum	Range	Quartile Range	Standard deviation	Coefficient of variation	Skewness	Kurtosis
	2011								
synthetic measure of linear infrastructure	0.25	0.07	0.60	0.53	0.09	0.13	51.93	1.60	3.06
expenditures transport and communications	172.52	135.48	240.81	105.33	46.13	32.98	19.12	0.92	-0.02
expenses - voivodship public roads	99.24	41.25	150.34	109.09	31.79	30.06	30.29	0.20	-0.07
roads for bicycles	1.91	0.83	4.54	3.71	1.51	0.98	51.56	1.17	2.04
public roads	134.03	83.30	214.50	131.20	34.50	34.85	26.00	0.98	1.13
expressways and highways	0.61	0.00	1.98	1.98	0.62	0.52	84.59	1.15	1.99
bridges and viaducts	12.13	5.00	33.00	28.00	7.50	8.50	70.10	1.56	1.40
railroads	6.96	3.80	17.40	13.60	2.00	3.17	45.50	2.58	8.28
	2021								
synthetic measure of linear infrastructure	0.39	0.31	0.56	0.26	0.07	0.08	19.97	1.27	0.87
expenditures transport and communications	232.34	147.18	358.48	211.30	65.66	55.32	23.81	0.97	0.50
expenses - voivodship public roads	126.22	69.88	247.46	177.58	54.90	45.10	35.73	1.33	2.31
roads for bicycles	5.92	3.08	11.10	8.02	3.45	2.14	36.16	0.91	0.70
public roads	138.74	85.60	207.50	121.90	35.75	33.32	24.02	0.59	0.52
expressways and highways	1.49	0.81	2.95	2.14	0.81	0.66	44.11	1.15	0.61
bridges and viaducts	13.69	6.00	36.00	30.00	7.50	9.04	66.04	1.57	1.46
railroads	6.61	3.80	15.20	11.40	1.95	2.67	40.38	2.39	7.27

Effective transport infrastructure is crucial for the economy and society, but it also impacts the environment in various ways. Between 2011 and 2021, measures of central tendency (mean) increased (except for railways), while variability measures (standard deviation, coefficient of variation) showed both increases and decreases. Higher kurtosis values indicate a more concentrated distribution around the mean, while lower kurtosis reflects a wider spread of values. The synthetic measure showed left skewness for variables like bicycle roads, public roads, and railways (AS<0), and right skewness for transport and communication, spending on provincial roads, expressways, motorways, and bridges (AS>0). Left skewness means more units have values above the mean, while right skewness indicates the opposite. The degree of skewness reflects the distribution's asymmetry (Table 3).

Central and Eastern European countries have significant deficiencies in transport infrastructure, which affects economic development and production. Transport infrastructure should be evaluated both as a whole and by transport mode. Key factors for analysis include the level of transport, internationalisation, infrastructure quality, and efficiency of services. Among EU countries, the Netherlands leads in transport development, while Bulgaria ranks lowest. The Baltic States lag in transport internationalisation compared to EU leaders such as Germany, the UK, and Spain [28].

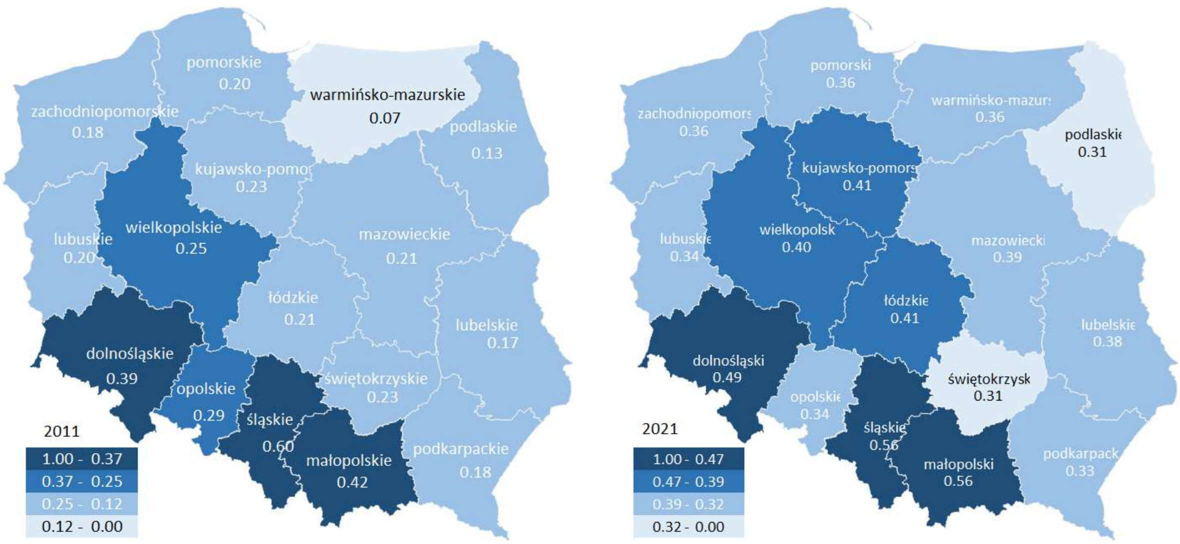

Figure 1 Division of provinces according to the value of the measure synthetic attractiveness of linear infrastructure of provinces in Poland in 2011 and 2021

The voivodeships with well-developed linear (transport) infrastructure include Śląskie, Dolnośląskie, and Małopolskie, where increased spending on public roads and the development of expressways and motorways are evident. These investments are crucial due to the underdeveloped railway network and the growing demand for both passenger and freight transport. Voivodeships such as Podlaskie and Świętokrzyskie, while showing progress in road infrastructure development, still lag economically and fail to fully capitalize on the advantages of a developed road network. Transport infrastructure plays a vital role in enhancing economic competitiveness, innovation, and territorial cohesion. As a result of insufficient transport infrastructure, areas with low spatial accessibility have emerged in Poland's regional and national system. Based on the mean value and standard deviation, the provinces were categorized, with darker colors indicating better-performing regions according to the primary criteria and lighter colors reflecting weaker regions (Figure 1).

In the voivodeships, expenditure on infrastructure development accounts for a significant part of the budget and is one of the most anticipated investments by the local community. The directions of development of transport infrastructure may include revitalisation, modernisation or construction of new transport routes. The length and density of the road network varies by province. The values of the individual indicators differ considerably, which is due to various conditions, the most important of which seem to be historical-geographical factors, the difference in area, the difference in population and the different economic characteristics of the provinces. The geographical indicator (per 100km2) was the highest in both Śląskie and Małopolskie voivodeships, and the lowest in Warmińsko-Mazurskie, Zachodniopomorskie, Lubuskie and Podlaskie. Other results, which are sometimes the inverse of the geographical indicator, occurred in the case of the demographic indicator, which is due to the population size of Polish voivodeships [29].

There is a systematic increase in the demand for transport in Poland. This is due to an increase in the volume of production, international exchange, concentration of production and service activities, changing lifestyles and increased mobility of the population. At the same time, despite the considerable involvement of the administration in the development of the road system, the quantitative and qualitative development of the road infrastructure and its condition are not adequate to Poland's expectations. The development of the road infrastructure will become increasingly difficult, the construction of new roads is not only a significant investment, it is also an often difficult to accept transformation and occupation of land. It is therefore becoming necessary to make better use of the existing road infrastructure [30]. It is therefore necessary to complete the road infrastructure in the east of our country as soon as possible.

The values of the individual indicators differ significantly from each other, which is due to various conditions, of which the most significant seem to be historical-geographical factors, the difference in area, the difference in population and the different economic specificities of the provinces. In terms of these variables, the provinces of group I are in a better situation than the others. The length and density of the road network varies from voivodeship to voivodeship in Poland (group I units are in a better situation, group IV units in a weaker one).

Figure 2 illustrates the relationship between the synthetic measure of linear infrastructure and two key indicators: gross domestic product (GDP) per capita and per capita household transport expenditure. The chart highlights the differentiation among voivodeships based on these factors, identifying outliers that belong to Group I, which stand out in terms of their unique characteristics. The shape and distribution of these groups in subsequent years may reveal trends of convergence or divergence, reflecting the evolving disparities or improvements in infrastructure development and its impact on economic performance and household transport expenditure across the regions.

Table 4 The average value of the synthetic measure and diagnostic variables by synthetic measure group attractiveness of linear infrastructure of voivodships in Poland in 2011 and 2021

groups	I	II	III	IV	I	II	III	IV
	2011				2021			
synthetic measure of linear infrastructure	0.47	0.27	0.19	0.07	0.54	0.41	0.36	0.31
number of units	3	2	10	1	3	3	8	2
expenses on transport and communications	184.56	183.67	169.42	145.09	221.2	190.43	252.01	233.24
expenses - voivodship public roads	93.74	94.1	105.13	67.14	112.91	103.68	132.19	156.08
roads for bicycles	2.79	2.5	1.63	0.88	7.35	7.09	5.49	3.74
public roads	177.53	127.3	126.17	95.5	178.9	146.13	119.98	142.45
expressways and highways	1.28	0.88	0.39	0.3	2.16	1.96	1.21	0.86
bridges and viaducts	28	11.5	8.1	6	30.67	9	10	10
railroads	11.23	8.1	5.64	5.1	10.4	6.3	5.71	5
gross domestic product per capita	41656.3	37719.5	35745.6	29175	70138.7	65425	61225.1	50339.5
household transportation expenditures (average monthly expenditure per person)	98.05	92.14	91.49	65.49	132.48	110.27	123.2	101.56

The role of infrastructure in the economic development process consists mainly in creating the conditions for production activities. The lack of transport infrastructure may be the cause of the marginalisation of regions, i.e. their exclusion from development processes and thus the exclusion of their inhabitants. It increases the production capacity of an area by increasing accessibility to resources, as well as extending the productivity of already existing resources. The influence of the diagnostic variables of the synthetic measure of lion infrastructure, gross domestic product per capita and per capita household transport expenditure on the level of the synthetic measure is presented in Table 5.

Table 5 Correlation of the synthetic measure of lion infrastructure attractiveness and the diagnostic variables of voivodships in Poland in 2011 and 2021 (Marked correlation coefficients are significant with p < .05000; N=16)

	synthetic measure of linear infrastructure							
	Pearson's linear correlation coefficient		Spearman's rank correlation coefficient		Gamma correlation coefficient		Kendall's tau correlation coefficient	
	2011	2021	2011	2021	2011	2021	2011	2021
expenses on transport and communications	0.03	-0.14	0.01	-0.11	0.03	-0.07	0.03	-0.07
expenses - voivodship public roads	-0.28	-0.27	-0.24	-0.33	-0.20	-0.25	-0.20	-0.25
roads for bicycles	0.72	0.53	0.61	0.54	0.52	0.38	0.52	0.38
public roads	0.76	0.70	0.56	0.55	0.40	0.35	0.40	0.35
expressways and highways	0.83	0.64	0.82	0.67	0.66	0.50	0.66	0.50
bridges and viaducts	0.93	0.82	0.68	0.28	0.56	0.21	0.55	0.21
railroads	0.89	0.68	0.88	0.45	0.73	0.32	0.73	0.32
gross domestic product per capita	0.35	0.38	0.64	0.61	0.45	0.40	0.45	0.40
household transportation expenditures (average monthly expenditure per person)	0.23	0.22	0.39	0.30	0.30	0.20	0.30	0.20

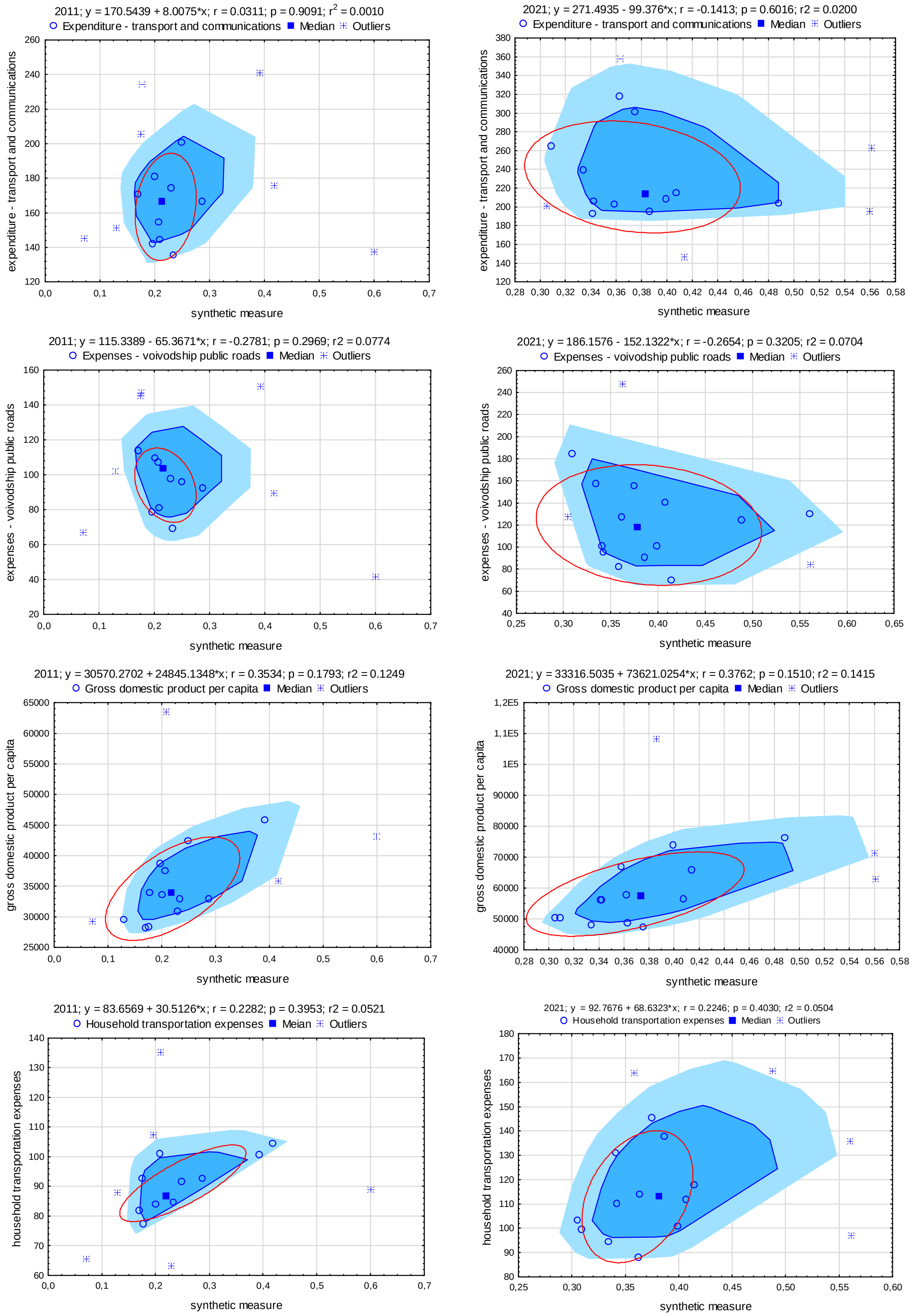

Figure 2 Scatter plot with fit line for the synthetic measure of attractiveness of linear infrastructure and the diagnostic variables of linear infrastructure of voivodeships in Poland in 2011 and 2021

The Gini coefficient of concentration (Table 6) reflects changes in the differentiation of voivodeships, showing either increasing or decreasing inequality. A higher Gini coefficient indicates greater regional disparities in terms of transport infrastructure, while a lower value suggests more equal development across regions. Barriers to improving transport infrastructure within voivodeships include the local economy's state and structure, as well as factors related to quality of life and environmental conditions. Additionally, historical development patterns, political decisions, and funding allocation can also impact the pace and extent of infrastructure improvements, further contributing to regional disparities. Overcoming these barriers requires targeted policy interventions and investments aimed at reducing inequalities.

Table 6 The Gini coefficient for the synthetic measure and diagnostic variables of the linear infrastructure of voivodships in Poland in 2011 and 2021

	2011	2021
	Gini coefficient	
synthetic measure of linear infrastructure	0.38	0.23
expenses on transport and communications	0.23	0.25
expenses - voivodship public roads	0.29	0.31
roads for bicycles	0.39	0.32
public roads	0.26	0.25
expressways and highways	0.57	0.35
bridges and viaducts	0.46	0.44
railroads	0.33	0.31
gross domestic product per capita	0.24	0.25
household transportation expenditures (average monthly expenditure per person)	0.22	0.23

A robust and efficient infrastructure is essential for the smooth functioning of the economy. In countries with high infrastructure quality ratings, such as Germany and the UK, well-established investment mechanisms are in place. These mechanisms provide benchmarks for decision-making and the assessment of investment effectiveness [31].

Infrastructure consolidations are characterized by a small average area and often face difficulties in building linear infrastructure, which can be a barrier to development. Infrastructure consolidation also provides opportunities to create public spaces and improve transportation and drainage networks, which supports rural development [32].

Transportation plays a key role in promoting social cohesion, creating connections between people and their needs. Transportation systems are usually evaluated in terms of economic efficiency, but sustainable urban development requires access to (sustainable) transportation. With rising real estate prices (e.g., housing), people with lower incomes may have to rely on cars, undermining sustainability goals. It is therefore important to better integrate transportation and land use planning [33].

5 Conclusions

Despite the ongoing intensive development of linear infrastructure, significant disparities remain between Poland's voivodships. The quality and extent of transport infrastructure are considered crucial factors for the economic development of both cities and entire regions. Well-developed infrastructure not only facilitates trade but also enhances the mobility of labor, which positively influences the flow of human resources. Furthermore, improved transport systems contribute to reducing regional disparities by providing more equitable access to economic opportunities, thereby strengthening the overall competitiveness of regions.

The synthetic measure of linear infrastructure ranged from 0.01 (warmińsko-mazurskie) to 0.60 (śląskie) in 2010 and 0.31 (świętokrzyskie, podlaskie) to 0.56 (śląskie, małopolskie) in 2021. The provinces well equipped with linear (transport) infrastructure include the provinces of śląskie, dolnośląskie, małopolskie. Voivodeships where road connections are visibly developing include podlaskie, świętokrzyskie.

Regional authorities constantly face challenges arising from a dynamic economic, technical, sociocultural, and natural environment. To effectively address these challenges, it is crucial to ensure not only rapid but also balanced and sustainable development of infrastructure across regions. Ongoing monitoring and analysis of linear infrastructure are essential for authorities to assess and adjust their policies based on real-time data, especially regarding the disparities between provinces. The changes observed in synthetic measures should be used as a tool for evaluating the outcomes of previous management strategies, particularly in terms of their impact on the key infrastructure indicators. A major concern for many regions, especially in relation to infrastructure, is depopulation. To counter this trend, authorities study demographic and migration patterns and assess residents' satisfaction with life in the region. In future studies, it will be important to incorporate additional variables such as the transition to a green economy, the expansion of green infrastructure, and the broader impacts on quality of life and the environment. These factors are vital for ensuring sustainable development and improving the living standards of local communities.

The limitations of the research conducted on on the evaluation of linear infrastructure are primarily related to the availability and accessibility of data within the framework of the Statistics Poland. Additionally, challenges arise from the comparability of the variables used to describe the phenomenon being studied, as some variables may differ across regions or over time. Changes in legislation, which can affect the interpretation and collection of data, further complicate the research process. Moreover, the scope of tasks and responsibilities carried out by provincial authorities can vary, influencing the extent to which infrastructure development and other factors are addressed. These factors collectively present challenges in ensuring consistent and accurate analysis across different regions and time periods.

The value of this article lies in the presentation of the results regarding the spatial differentiation of linear infrastructure for the years 2011 and 2021. The findings contribute to ongoing discussions surrounding the development and condition of a country's linear infrastructure, as well as its broader environmental context. This topic gains particular relevance in light of the European Green Deal, which emphasizes the transition to cleaner, more sustainable forms of transportation. By examining infrastructure trends over the past decade, the article provides valuable insights into how transport networks can evolve to align with the goals of environmental sustainability, economic growth, and the reduction of carbon emissions.

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