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Disparities in the level of regional technical infrastructure development in Poland: multicriteria analysis

JEL Classification: *O11; R11; R58*

Keywords: *regional infrastructure; regional disparities; Poland's voivodeships; taxonomic analysis; multicriteria analysis; Hellwig development pattern method*

Abstract

Research background: The development policy currently promoted by the European Union is focused on the use of the territory's internal resources. Among the factors affecting regional development, by building its potential, infrastructure, being a basic necessity for developing activity in a given area, is of significant importance. Hence, investment in infrastructure is critical to stimulating economic dynamism, as it is the basis for supporting a variety of measures aimed at economic growth.
Purpose of the article: This paper aims to evaluate the level of development of technical infrastructure and changes taking place in this field in Polish voivodeships in 2008 and 2020.
Methods: The study was carried out using the Hellwig development pattern method and a comparative analysis of the technical infrastructure of Polish regions. The above approach makes it possible to measure the diversity of the state and availability of infrastructure for the communities of the regions.
Findings & value added: While implementing the study aim, particular attention was paid to the spatial differences in the level of development of the technical infrastructure of Polish voivodeships. The analysis enabled to distinguish groups of voivodeships with the highest, high, low, and very low level of technical infrastructure development. From a long-term perspective, the conducted research can be seen as a contribution to existing research and serve to further compare the impact of technical infrastructure on the economic development of countries. The strength of the study is the adequately long time span of the analysis (2008 — the period of the financial crisis and 2020 — the COVID 2019 pandemic), which provides a basis for the formation of the infrastructure in question. The added value of the article is also a regional perspective on the level of

development of technical infrastructure using multidimensional methods of statistical analysis. The results of the study can be used to make decisions at the national level regarding the retrofitting of infrastructure in regions with a low level of infrastructure development. For the European Union's decision-makers they can be a source of knowledge of where to direct EU funds the purpose of which is the infrastructural development of regions.

Introduction

Development, as a complex and multidimensional concept, is determined by many factors, such as human capital, regional economy structure, innovation plus research and development activity, regional entrepreneurship, investment attractiveness, infrastructural development, and natural environment. Among a wide range of development factors, significant importance is attached to infrastructural equipment, especially in territorial units that are characterized by low levels of socio-economic development. The functioning and existence of people without a well-developed and accessible infrastructure seems impossible at the moment. Providing a good-quality technical infrastructure consequently affects the sustainable socio-economic development of a given region[1].

This paper aims to evaluate the level of development of selected elements of technical infrastructure and changes taking place in this field in Polish voivodeships in 2008 and 2020. In the author's opinion, there is a shortage of analyses that would empirically verify the spatial differences in the level of technical infrastructure development in Polish voivodeships[2]. Most publications concern individual elements of technical infrastructure, e.g. transport infrastructure, environmental protection, telecommunications. Therefore, technical infrastructure was selected as the subject of study.

The criterion for selecting the time scope of the analysis was full access to current statistical data — 2020 and 2008 — which was a reference point for presenting the changes in the level of technical infrastructure development in Polish voivodeships. In addition, the temporal scope of the analysis includes financial perspectives of the European Union (2007–2013 and 2014–2020), which indicate the possibility of using European funds that also co-finance the modernization and development of technical infrastruc-

[1] The implementation of the Sustainable Development Goals included in the 2030 Agenda will also depend on infrastructure resources. Hence, there is currently a relatively new concept, i.e. sustainable infrastructure (Transforming our world: the 2030 Agenda for Sustainable Development).

[2] The importance of infrastructure is reflected in the approximate indicators of publication numbers, e.g. the Web of Science resources indicated a 40-fold increase in the number of articles on infrastructure and regions over the last 20 years, and 3.5 times more articles in 2018 than in 2009: 2677 compared to 764 (Glass *et al.,* 2019, p. 1651).

ture elements. The research was conducted using data from the Local Data Bank, made available by Statistics Poland.

This paper aims to contribute to the considerations, in the aspect under study, in two ways. Firstly, it provides a sound theoretical framework for the development of infrastructure, including technical infrastructure, based on the available current literature. Secondly, it empirically verifies the spatial variation in the level of development of technical infrastructure in Polish regions. The results of the study are important for governmental and regional institutions and other stakeholders who play an important role in preparing programs to raise the level of development of technical infrastructure and its importance in the socio-economic development of countries. The strong point of the study is the adequately long time span of the analysis, and from a long-term perspective the research can provide a basis for further comparative analyses of the influence of technical infrastructure on the development of the economies of countries.

To evaluate the level of development of technical infrastructure in Polish regions, the Hellwig development pattern method was used (Hellwig, 1972, pp. 115–134), which enabled to organize the voivodeships according to the level of development of the analyzed infrastructure. The supplement is a comparative analysis of infrastructure in Polish voivodeships. The above approach made it possible to measure the diversity of the state and availability of infrastructure for the regional community.

The structure of the article was subordinated to the fulfillment of its objective and it is divided into a theoretical and an empirical part. The first part discusses the conceptual scope of technical infrastructure and the Hellwig development pattern method, which is the analysis tool. Then, the diagnostic variables used in the study were characterized. In the analytical part, the level of development of regional infrastructure in Polish voivodeships was determined. The final chapter of the article contains conclusions.

Literature review: technical infrastructure as an economic category

As a member of the European Union, Poland pursues the goals of improving both its competitiveness and that of the entire group. One of the pillars of the competitiveness of EU member states' economies is infrastructure, which, according to The World Economic Forum, constitutes one of the basic conditions ensuring opportunities for economic growth and raising standards of living. Thus, infrastructure investments are fundamental to stimulating the economic strength of the region, as they are the basis for supporting a variety of activities that will result in economic growth. Attention to increasing accessibility and higher quality infrastructure leads to a higher productivity of manufacturing factors. On the other hand, its low level, or even lack thereof, is a significant obstacle in the effective implementation of development policies, and thus in achieving levels of sustainable growth.

In a dynamically developing economy, the technical infrastructure is one of the basic elements of the social and economic life structure. This term is the subject of turbulent discussions focused on the broadly understood social and economic development of Polish regions. The level of development of technical infrastructure is treated as one of the main indicators of the development potential of individual units, both at the regional and local level.

Based on the study conducted so far, it can be indicated that infrastructure is analyzed in terms of its impact on regional development, economic growth, labor productivity, regional competitiveness, income inequality, environmental impact, and welfare. Many researchers point to the relationship between infrastructure and regional development, which is an important public policy issue (Haynes *et al*., 2017). A proper understanding of the dependencies between infrastructure and regional development requires not only knowledge of the mechanisms of influence and reference to relevant economic theories, but also the use of geographic and spatial analysis methods to identify these connections. Nijkamp (1986, pp. 1–21) argues that infrastructure policy is a prerequisite for regional development policy. Although it does not guarantee regional competitiveness, it creates the conditions necessary to achieve the goals of regional development. His research focuses on the role of infrastructure in implementing regional development strategies. Rojas Ramírez and Molina Vargas (2018, pp. 4–27) conduct a case study of Oaxaca, Mexico, in 2003–2013, to estimate the impact of public infrastructure on economic growth. Research results show that the most dynamic regions require greater investment in economic infrastructure, while lagging regions need social infrastructure. The assessment of the impact of technical infrastructure on regional development should also take into account protected areas (Kulczyk-Dynowska & Stacherzak, 2020, pp. 1–14). The indicated analysis illustrates the impact of the degree of this infrastructure development in areas valuable both in terms of nature and attractive to tourists. The development of these territories is highly dependent on environmental factors and the level of infrastructure is the basis of sustainable development. Another research approach indicates the connection of infrastructure development with selected socio-economic characteristics of a territorial unit, where the relative wealth of the local administrative unit stimulates the development of infrastructure (Gospodarowicz, 2015, pp. 147–154).

Many researchers focus on the urban level for infrastructure development. Some assess cities using the level of services and the dynamics of changes in the field of technical infrastructure as a measure (Pawłat-Zawrzykraj & Podawca, 2018, pp. 1–8) and, consequently, they present the spatial diversity of urban units with a high, medium, and low rate of development of technical infrastructure. On the other hand, Rutherford (2020), based on the case study of urban infrastructure in Stockholm and Paris, developed an innovative conceptual framework extremely important for studying the role of infrastructure in constituting urban development policy.

Other authors examine individual elements of technical infrastructure (e.g. transport, environmental protection, or telecommunications), emphasizing that they constitute an important factor in creating, maintaining, and promoting economic growth, and consequently contributing to the improvement of the inhabitants' quality of life (Vlahinić Lenz *et al.*, 2018, pp. 1953–1964; Shi *et al.*, 2017, pp. 26–41; Wang *et al.*, 2020, pp. 288–307; Ramzan *et al.*, 2013, pp. 293–300).

However, some studies show that transport infrastructure alone is not sufficient to achieve a higher gross domestic product, and infrastructure equipment represents a relatively low rate of economic growth (Canning & Pedroni, 2008, pp. 504–527). According to Mamatzakis (2008, pp. 307–326) infrastructure is one of the most important components of economic activity in Greece. His research shows that public infrastructure reduces costs in most manufacturing industries and increases resource efficiency. In contrast, the research of Aschauer (1989, pp. 177–200) suggests that reducing public investment in transport infrastructure causes a significant decline in productivity growth. Efficient infrastructure supports economic growth, improves the quality of life, and is important to national security (Baldwin & Dixon, 2008). Some authors are surprised by the analyses, showing that although infrastructure investment promotes economic growth, theories of macroeconomic growth do not directly cover the concept of infrastructure systems. Carlsson *et al*. (2013, pp. 263–273) attempted to fill this research gap and researched the role of infrastructure in macroeconomic growth theories. They confirmed that certain economic functions of infrastructure can be represented in existing macroeconomic models and that the new economic geography, as it grows, makes it possible to present transport infrastructure in the context of a more spatial approach. On the other hand, the work of Grzyb and Trzepacz (2012, pp. 94–100) shows that investments in transport infrastructure are the key to improving the role of entrepreneurship in the development of the country and the region, as well as the relationship between the number of enterprises and the quality and spatial importance of transport infrastructure. Transport infrastructure, which is one of the key elements of the development and cohesion strategy both in the European Union and in the world, was reflected also in the research of Crescenzi and Rodríguez-Pose (2012, pp. 487–513). The paper deals with the issue of the extent to which the endowment of transport infrastructure contributed to the regional development in the EU in the years 1990–2004. The infrastructure was investigated in relation to factors that can determine economic growth, such as innovation, migration, and the local community. The results show that infrastructure endowment is a relatively weak predictor of economic growth and that regional growth in the EU is the result of a combination of levels of human capital, good innovation capacity, both in the region and in neighboring areas, and the region's ability to attract human capital.

Palei (2015, pp. 168–175) in her research presented the degree of influence of infrastructure on the country's competitiveness. According to the author, effective infrastructure management can improve industrial policy and thus increase the level of competitiveness at the national level. Snieška and Bruneckienė (2009, pp. 45–57) identify infrastructure as one of the regional indicators of the country's competitiveness. On the other hand, Martinkus and Lukasevicius (2008, pp. 67–83) argue that physical infrastructure and infrastructure services are factors that shape the investment climate at the local level and affect the region's attractiveness.

The effective functioning of transport largely determines the effectiveness of the national economy and economic growth, as well as the sustainable development of regions. Therefore, in infrastructure research, it is important to establish the relationship between the welfare factors of the population and the level of development of the transport infrastructure in the country (Popova, 2017, pp. 579–588; Arimah, 2017, pp. 245–266). Aschauer (1989, pp. 177–200) also emphasizes that public infrastructure is the basis of the quality of life.

Infrastructure is often mentioned as a development factor which is important both in initiating development and influencing the course of development processes. Due to the multitude of elements making up the infrastructure, it is a difficult concept to define unequivocally. Therefore, the literature on the subject does not adopt a single, universally accepted term. Kuciński (2009, p. 149) points out that infrastructure is a "*system of devices, facilities and institutions serving and connecting spatial systems into one whole*". However, according to Stawasz (2005, p. 7), infrastructure includes "a set of specific devices, networks, buildings and systems not directly related to the production of material goods, but necessary for the implementation of the production process itself, as well as the life of the population".

The literature on the subject usually lists tangible and non-tangible infrastructure. Infrastructure occupies a special place in regional development management due to its features, i.e. servitude, durability, open access, high capital intensity, immobility, step-wise method of cost generation and a long period of capital freeze (Kuciński, 2009, p. 149). The importance of infrastructure in local and regional development is confirmed by the functions it performs, including service, transfer, integration, location, and acceleration functions.

Technical infrastructure, which is the subject of the research, consists of the following systems: transport (by road, rail, air, and water, including sea), water and sewage, power, communication, environmental protection, as well as municipal management equipment, warehouses, cold stores, trade equipment, and logistics centers (Stawasz, 2005, p. 8). The presented exhaustive definition of technical infrastructure was the basis for selecting the diagnostic variables analyzed in this study.

To conclude, the analysis of the regions in terms of infrastructure (including the technical infrastructure that is its component) provides a new, necessary look at the regional issue and generates a new quality of interdisciplinary research on the issues of shaping urban, national, regional, or European space. The possibilities resulting from the analysis of the current state of infrastructure and the challenges facing the economies of countries provide the basis for the continuous assessment of research trajectories considered at the intersection of regions and infrastructure in regional studies (Glass *et al.*, 2019, p. 1651). This is confirmed by the proposal of future research presented by Wiig and Silver (2019, pp. 912–923), in which the key analysis concerns the distribution of global infrastructure to study the level of urbanization in uncertain geopolitical times.

Research method

Diagnostic features adopted for the research on the level of development of technical infrastructure

In this study, selected elements of regional technical infrastructure are analyzed. To effectively measure the level of technical infrastructure development, it is necessary to select appropriate diagnostic variables. This is also a prerequisite for multidimensional comparative analysis. The analysis covered 16 Polish voivodeships and the years 2008 and 2020. The selection of features explaining the level of development of the regional technical infrastructure derives from the aim of the study and the methods of analysis, and it is a result of both the availability of data and the arbitrary decisions of the researcher. The most general groups of criteria for selecting diagnostic variables for the development of technical infrastructure include: content-related, formal, and statistical (Strahl, 2006, p. 33). Taking into account the current literature on the subject and own experience in the discussed scope of analysis, the author of the paper has defined a list of features corresponding to the need to examine the level of technical infrastructure development in Polish regions. An additional criterion in this respect is the timeliness, availability, and comparability of data covering the analysis of the studied phenomenon in 2008 and 2020. The Statistics Poland data used comes from: Local Data Bank of Statistics Poland, Statistical Yearbook of Voivodeships for 2010 and 2020, advance information entitled "Information Society in Poland in 2014", and advance information entitled "The use of information and communication technologies in public administration units, enterprises and households in 2020"[3].

In the first stage of the research, a set of 14 diagnostic variables was proposed as a result of a substantive and formal analysis of the variables[4] (Table 1). These variables should be characterized by high diversity and low correlation with other variables. Therefore, the set of potential diagnostic variables (all of them being stimuli) was subjected to statistical verification with respect to their variability and degree of correlation. Adopting the threshold value of the coefficient of variation at the level of $V \geq 10\%$ meant that from the set of potential diagnostic variables it was necessary to eliminate those for which the coefficient of variation was lower, i.e. the following five variables: X_4, X_5, X_7, X_{10} and X_{13}. Then, to determine the degree of correlation between the variables, the Hellwig parametric method was used (Hellwig, 1968, pp. s. 307–326) with the threshold value of Pearson's linear correlation coefficient set arbitrarily at the level $r^*=0.7$. Feature X_8 – Population using the sewerage system in % to the total population [%], for which the coefficient was lower than the established value, was excluded from the set of variables. Ultimately, 8 diagnostic variables were adopted to achieve the objective of the study, two of which are central variables: X_1, X_{11}, and the other six: X_2, X_3, X_6, X_9, X_{12} and X_{14} are isolated variables.

[3] It should be noted that the value of feature X_5 – Households with access to the Internet for 2008 comes from 2014, due to the incompleteness of data characterizing this aspect of the analyzed infrastructure.

[4] Due to lack of data continuity, the following was used as the X_6 variable for 2020: Subscriber lines per 1,000 population (Local Data Bank, Statistics Poland, 2020. Retrieved from https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica).

Linear ordering methods

In order to capture the degree of equipment of regions with technical infrastructure, the Hellwig's development pattern method was used. It belongs to the group of taxonomic methods of linear ordering used to assess the multi-characteristic level of a phenomenon based on an aggregated synthetic indicator, which is the basis for the hierarchy of the studied objects.

The first stage in the construction of Hellwig's taxonomic measure is the selection of diagnostic variables and the determination of their characteristics. The nature of the variables was determined based on the merits. The verification of the adopted nature of the variables was carried out *ex-post*, checking the correlation of individual variables with the synthetic variable (Wierzbicka, 2018, p. 182; Korzeb & Niedziółka, 2020, pp. 213–214). In this research, only stimuli form variables[5].

Then, the values of individual indicators were normalized. It allowed to obtain comparability of diagnostic features by changing their natural units. In this study, normalization of features was applied through classic standardization[6] of variable value according to the following formula (for stimuli):

$$Z_{ik} = \frac{x_{ik} - \bar{x}_k}{s_k} \quad \text{for } (i = 1, \ldots, n;\ k = 1, \ldots, m) \tag{1}$$

where:
I set of stimuli;
Z_{ik} standardized value of feature k for country i;
x_{ik} value of feature k in country i;
$\bar{x}_k$ arithmetic mean of variable k; S_k - standard deviation of variable k;
m number of variables;
n number of countries.

[5] The selected variables were treated as equal, assuming a unit weight system.

[6] The standardization was carried out taking into account the arithmetic mean and standard deviation determined for the whole research period. Thus the synthetic measure of infrastructure development can be comparable over time. In this way the analysis takes on a dynamic character (Zeliaś, 2000).

In the next stage, the development pattern was determined for both analyzed years (abstract object P_0). It is characterized by the highest values for the stimuli and has standardized coordinates:

$$P_0 = [z_{01}, z_{02}, ..., z_{0k}] \quad (2)$$

where:

$Z_{0k} = \max\{z_{ik}\}$ — when x_k is a stimulus.

On the basis of Formula 3, distances between Polish regions and P_0 pattern (Euclidean distance) were calculated:

$$c_{i0} = \sqrt{\sum_{k=1}^{m}(z_{ik} - z_{0k})^2} \qquad i = 1, 2, 3, ..., n \quad (3)$$

In order to normalize the value of d_i indicator, a relative taxonomic development meter was constructed, which was calculated according to the following formula:

$$d_i = 1 - \frac{c_{i0}}{c_0} \quad , i = 1, 2, 3, ..., n \quad (4)$$

where:

$$c_0 = \overline{c}_0 + 2 \cdot s_0 \quad (5)$$

$\overline{c}_0, s_0$ arithmetic mean and standard deviation of c_{i0} sequence, respectively (i = 1, 2, 3, ... n);
d_i synthetic indicator;

whereas:

$$\overline{c}_0 = \frac{1}{n} \cdot \sum_{i=1}^{n} c_{i0} \quad (6)$$

and

$$s_0 = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n}(c_{i0} - \overline{c}_0)^2} \quad (7)$$

The synthetic measure of development d_i (4) obtained as a result of the calculations assumes values from 0 to 1 range. The closer the value of d_i measure is to 1, the less distant the object (region) is from the pattern and has a higher level of technical infrastructure development. Therefore, a voivodeship which achieved a higher level of this indicator is considered to be better equipped with infrastructure compared to regions which achieved lower values.

Results

The potential of Polish regions in terms of technical infrastructure: comparative analysis

The issue of evaluating the potential of Polish regions in terms of technical infrastructure understood as their ability to increase the condition and quality of infrastructure resources requires the characterization of the infrastructure equipment in the surveyed voivodeships. The selected variables for technical infrastructure development level determine: the quality of roads (feature X_1); the density of railway network (features X_2 and X_3); the level of information transmitted (feature X_6); the level of equipment with gas networks; wastewater treatment plants and devices reducing emissions of gas pollutions (features X_9, X_{11}, X_{12} respectively); and traffic density at airports (feature X_{14}). The discussion on the potential of Polish regions in the field of infrastructural retrofitting was limited to the finally selected diagnostic features (Table 2).

In terms of the quality of roads (variable X_1), which testifies to the transport infrastructure, the following regions ranked best in 2020: Śląskie — 181.9 km/100km^2, Małopolskie — 172.2 km/100km^2, Świętokrzyskie — 126.2 km/100km^2, and Łódzkie — 116.9 km/100km^2. All of the above voivodeships exceeded the average for Poland — 100.3 km/100km^2 (83,5 km/100km^2 in 2008) in both of the analyzed years. The following voivodeships ranked the lowest: Warmińsko-Mazurskie — 59.3 km/100km^2, Lubuskie — 69.2 km/100km^2 and Podlaskie — 70.5 km/100km^2.

The density of the railway network (variable X_2), which is also a determinant of the transport infrastructure, indicated in 2020 the voivodeships with the highest value of the indicator: Śląskie — 15.5 km/100km^2, Dolnośląskie — 8.7 km/100km^2, Opolskie — 8.4 km/100km^2, and Małopolskie — 7.1 km/100km^2. The average value of this variable for Poland in 2020 was 6.2 km/100km^2. The least favorable density of railway network was recorded in the following regions: Podlaskie — 3.7 km/100km^2, Lubelskie — 4.3 km/100km^2, and Warmińsko-Mazurskie — 4.7 km/100km^2. Both of these indicators show the intensity of investment in transport infrastructure.

The value characterizing the field of communication is the level of information transmitted (variable X_6). In terms of this feature, the following voivodeships were at the top of the list in 2020: Mazowieckie — 129.4 (in 2008 — 316.0; this is the highest value in 2008), Pomorskie — 97.9, Małopolskie — 94.8, Opolskie and Dolnośląskie — 91.5. The average for Poland in the analyzed years was: 80.5 for 2020 and 241.8 for 2008. At the bottom of the list were: Wielkopolskie — 56.1, Świętokrzyskie — 57.4, Warmińsko-Mazurskie — 62.3, Łódzkie — 62.6, and Kujawsko-pomorskie – 65.9.

Population using the gas network in % of the total population [in %] (feature X_9) is a variable representing the level of gas network equipment. It assumed values ranging from 74.1% in the Podkarpackie Voivodeship, 64.8% in Małopolskie, 64.4% in Śląskie, 62.6% in Dolnośląskie and 61.0% in Zachodniopomorskie, through 54.2% in Poland (in 2008 — 51.7%). The lowest values were characteristic for the following regions: Podlaskie — 29.9% (in 2008 — 26.5%), Świętokrzyskie — 39.5% (in 2008 — 36.1%), Łódzkie — 40.1% (in 2008 — 39.2%) and Warmińsko-mazurskie — 42.7% (in 2008 — 43.9%).

Another variable — Industrial and urban wastewater treated in % of wastewater requiring treatment (feature X_{11}) characterizes the level of equipment and use of wastewater treatment plants. The best situation was recorded in the following voivodeships: Pomorskie, Opolskie and Warmińsko-mazurskie — 99.9%, Podlaskie — 99.6%, Wielkopolskie — 99.5%, and Zachodniopomorskie 99.1%, while the following regions ranked the lowest: Łódzkie — 59.5%, Śląskie — 69.6%, Świętokrzyskie — 82.5%, and Mazowieckie — 84.5%. The average value for Poland in 2020 was 86.6% (in 2008 — 92.9%). Variables $X_{6,}$ X_9 and X_{11} indicate the level of access to communication sections, gas networks, and wastewater treatment plants.

In terms of the reduction of gas pollution — variable X_{12}, the following regions ranked highest: Dolnośląskie — 96.1%, Lubelskie — 91.5%, Pomorskie — 90.6%, and Łódzkie — 88.8%. The above-mentioned voivodeships exceeded the average value of the variable for Poland, which amounted to 70.4% (in 2008 — 54.9%). The following voivodeships ranked the lowest: Warmińsko-Mazurskie — 3.7%, Śląskie — 23.6%, and Podlaskie — 30.9%. This variable indicates the awareness of regional communities in terms of the importance of environmental protection.

The development of technical infrastructure in the aspect of air transport was characterized by variable X_{14} — Passenger traffic at airports. In terms of the value of this feature, the following voivodeships ranked the best: Mazowieckie — 43.5% (in 2008 — 45.6%), Małopolskie — 17.8% (in 2008 — 14.0%), Pomorskie — 11.6% (in 2008 — 9.4%), and Śląskie — 9.9% (in 2008 — 11.7%). The lowest share was achieved by the following regions: Lubuskie — 0.1% (in 2008 — 0.0%), Warmińsko-mazurskie — 0.4% (in 2008 — 0.0%), Łódzkie — 0.5% (in 2008 — 1.7%), Lubelskie — 0.8% (in 2008 — 0.0%) and Kujawsko-Pomorskie — 0.9% (in 2008 — 1.4%). This variable indicates the volume of traffic at airports.

Differentiation in the level of technical infrastructure development in Poland's voivodeships: research results

The classification of voivodeships according to Hellwig's synthetic index showed great diversity in the development of their regional infrastructure (Table 3 and Figure 1). The difference between the maximum value of 0.418 (Śląskie) and the minimum value of 0.007 (Podlaskie) in 2008 amounted to 0.411. In 2020, these values were as follows: maximum: 0.376 (Dolnośląskie), minimum: 0.020 (Łódzkie), giving a difference of 0.356. The distance of the regions from the pattern from 2008 and 2020 is shown in Figure 1.

The regions with the most advantageously developed infrastructure are the Śląskie and Dolnośląskie Voivodeships in 2008, which were included in the group of voivodeships with the highest level of technical infrastructure development. In the second analyzed year, the Dolnośląskie Voivodeship took the first place (0.376), while the Małopolska region was promoted to the second position due to the condition of infrastructure resources (0.345). However, the distance between them, noticeable in 2008, slightly decreased in 2020 (respectively: 0.063 and 0.031). On the other hand, the lowest level of technical infrastructure development occurs in the voivodeships: Podlaskie and Warmińsko-Mazurskie, which in both analyzed years were ranked first and second respectively in the group with the lowest level of infrastructure development. The synthetic indicator for Podlaskie region in 2008 was less than 60 times lower compared to the leader of the ranking. In 2020, the value of the indicator for the Łódzkie Voivodeship was nearly 19 times lower compared to Dolnośląskie. However, in 2020 the distance between Podlaskie and the leader decreased and was only 14.5 times lower compared to Dolnośląskie.

Based on Hellwig's synthetic development pattern indicator, Polish regions were classified into four groups of voivodeships: those with the highest, high, low, and very low level of technical infrastructure development (Zeliaś, 2000). The results obtained indicate significant disproportions in the level of infrastructural resources of Polish regions, which is illustrated in Table 3 and Figure 1.

The group with a high level of development in 2008 is composed of the following voivodeships: Małopolskie, Opolskie, Mazowieckie, Pomorskie, Wielkopolskie, and Kujawsko-Pomorskie. The Opolskie Voivodeship, the smallest in terms of area and population (16th place in the country) comes as a surprise in this group. It seems that it may result from the level of investment expenditures incurred by this voivodeship in 2020 (the share of investment expenditures in property expenditures was 96.5%). In the next analyzed year, the size of this group was 7 units. This group included the Śląskie Voivodeship, which changed its leading position from 2008, and the Lubuskie Voivodeship, which advanced from group III. The most numerous group in 2008 was the third group, which consisted of the following four voivodeships: Zachodniopomorskie, Podkarpackie, Lubelskie and Świętokrzyskie. Unfortunately, an unfavorable change is noticeable in the Łódzkie region, which came last place in the ranking created for 2020, i.e. in the group of the least developed regions in terms of the analyzed technical infrastructure. In 2008, only the Warmińsko-Mazurskie and Podlaskie Voivodeships were characterized by the lowest level of technical infrastructure development, and in 2020, as already mentioned, the Łódzkie Voivodeship was included into this group. It should be remembered that the costs of construction of technical infrastructure investments in the Warmińsko-Mazurskie Voivodeship are higher than in other voivodeships due to longer distances and difficulties in the implementation of construction investments (e.g. forests, lakes, unstable post-glacial land, nature protection requirements).

Comparing the two analyzed years, it can be stated that the voivodeships of Eastern Poland invariably occupy the last positions in the rankings with the reservation that the following regions: Podkarpackie, Lubelskie and Świętokrzyskie belong to the group of voivodeships with a low level of development of technical infrastructure. An increase in the ranking position was noted in Warmińsko-Mazurskie and Podlaskie Voivodeships (respectively: from the 15th place to the 14th; from the 16th to the 15th) and for the first of the mentioned voivodeships a decrease in the synthetic indicator by 0.034, while for Podlaskie — an increase in the Hellwig index by 0.019. In the Lubelskie Voivodeship an increase in Hellwig's synthetic indicator was recorded (o 0.044), which resulted in a change from 14th position to 12th position in the ranking. In turn, Świetokrzyskie Voivodeship remained on the same 13th position in both analyzed years, but the synthetic indicator increased by 0.015. The analysis of the level of infrastructure development in Eastern Poland indicates that it is insufficient, while it is a necessary condition for economic activity.

Discussion

Comparative analyses of Polish voivodeships in terms of the level of technical infrastructure development serve to identify the most similar regions in terms of the adopted criteria. Numerous publications confirm that there are differences in the level of infrastructure development in territorial units (Chciałowski, 2018, pp. 23–29; Fageda & Olivieri, 2019, pp. 1609–1631; Dehghan Shabani & Safaie, 2018, pp. 49–63; Schindler & Kanai, 2021, pp. 40–51; Surówka *et al.,* 2021, pp. 1–23). The results of the studies are comparable, subject to variable positions for some regions. These inequalities affect the level of social and economic development of Polish regions, as, after all, technical infrastructure is one of the factors determining the social and economic development of territorial units (Miłek, 2018, pp. 487–507; Pietrzak & Balcerzak, 2020, pp. 310–318; Sobiechowska-Ziegert & Mikulska, 2013, pp. 200–209). Therefore, improving access to technical infrastructure is considered to be one of the main investment priorities of the development policy both at the national and local level.

The transformation of the European Union in all its Member States has resulted in changes in the geographical structure throughout its territory. Countries compete beyond their borders for European and international markets. Regional disproportions in economic growth and spatial distribution of economic activity have become an unquestionable reality. Infrastructure is an important factor that serves the socio-economic development of regions and eliminating the existing differences in this aspect. The literature emphasizes the impact of transport infrastructure on regional development, with particular emphasis on road and rail infrastructure, which are features for infrastructure research (feature X_1, X_2 and X_3). Crescenzi *et al.* (2016, pp. 555–582) assessed the relationship between the regional quality of governance and the profits achieved from the operation of various types of road infrastructure in the regions of the European Union. The results confirm that investments in highways (preferred by governments) deliver significantly lower returns than the simpler secondary roads. Furthermore, government institutions also influence the return on investment in maintaining transport. The significant contribution of transport infrastructure to regional convergence was indicated in the work of Fageda and Olivieri (2019, pp. 1609–1631). The paper assessed the level of development of roads, railways, seaports, and airports in Spain in the years 1980–2008, and additionally supplemented them with the conditions for allocating transport investments in regions. The research confirmed the positive contribution of roads to the regional convergence processes in Spain, with the proviso that only roads seem to have an impact on these processes, and the main driving force of transport investments was the equalization of the level of infrastructure equipment between different regions of Spain. Similarly, in the Polish regions infrastructure investments have served to reduce disparities in the level of development of the infrastructure resources in question. Undoubtedly, the infrastructural potential of the Polish voivodeships is constantly changing and the stimulation of infrastructural investments will result in an increase in the economic level of the country. Also Dehghan Shabani and Safaie (2018, pp. 49–63) in the conducted analyses confirm the positive and significant impact of road and rail transport infrastructure on economic growth in Iran's provinces, while the improvement of individual infrastructure has a spatial impact on the economic growth of other provinces. According to the authors, the results of the research indicate that the effects of diffusion overcome the effects of agglomeration. Similarly, Polyzos and Tsiotas (2020, pp. 5–23) and Ng *et al.* (2019, pp. 29–31) show that the development of transport infrastructure and other socio-economic factors contribute to economic growth. The first authors define the direction of the impact of transport infrastructure on economic and regional development.

The results of the statistical analysis carried out on the study of the level of technical infrastructure development in Polish voivodeships provide decision-makers with substantive knowledge that is necessary to make decisions of national importance. It is closely related to the management functions in terms of making decisions at the national level (e.g. Ministry of Infrastructure and Ministry of Development) regarding the distribution of infrastructure resources, spatial development. They can also be a source of information for the European Union in the context of infrastructure retrofitting (especially transport) and, consequently, they can help make decisions regarding financial support, i.e. directing EU funds to regions. On the other hand, decisions related to investing capital in Poland by foreign investors depend, among others, on investment attractiveness, with the technical infrastructure in question being its component. The indicated research results can be used for comparative analyses of Polish voivodeships with the regions of other countries, e.g. of the European Union. An example may be the research indicated by Chciałowski (2018, pp. 23–29), which compared the directions of investment in infrastructure in the Norte region in Portugal with investment expenditure on infrastructure in the Mazowieckie Voivodeship, or the comparison of technical infrastructure in the municipalities of Małopolskie Voivodeship and the Tarnava region in Slovakia (Surówka *et al.,* 2021, pp. 1–23).

Analyzing the economy of regions from the angle of infrastructure, i.e. both large, capital-intensive projects and more mundane infrastructure elements, is a necessary perspective on the regional issue; especially in the context of developing sustainable national infrastructure systems that are based on the goals of sustainable development (Thacker *et al*., 2019, pp. 324–331).

Conclusions

The proper functioning of the region's economy requires appropriate infrastructure serving social and economic development. Regional infrastructure, constituting one of the factors of social and economic development of regions, is also an important element stimulating social and economic activation of the environment. Elements of infrastructure such as roads, railways, communication, power grid, water supply, and sewage treatment plants improve not only the quality of life of the inhabitants but also contribute to increasing investment attractiveness and effectively prevent migration of educated workforce outside the region. Hence, the results of the assessment of spatial inequalities in the level of development of technical infrastructure can be used in the management of regional development. The analysis of the technical infrastructure carried out leads to the following conclusions.

There are clear differences in the level of development of the infrastructure in question in the Polish regions. The distance between the classification leaders and the last ranked regions (in 2008 — 0.411; in 2020 — 0.356) indicates significant spatial inequalities in the level of the analyzed infrastructure. The value of the synthetic indicator defining the level of development of technical infrastructure confirmed the distance separating the Śląskie Voivodeship from the Podlaskie Voivodeship (in 2008 this indicator was already over 60 times lower, while in 2020 it was only 14.5 times lower for the Podlaskie Voivodeship in relation to the leader). In 2020, nine voivodeships were characterized by the highest and high level of regional infrastructure, while in the first year of the study eight regions belonged to groups I and II, and eight belonged to the group with a low and very low level of development of technical infrastructure.

Noteworthy is the change in the case of the Mazowieckie, Lubuskie and Łódzkie Voivodeships. The former was promoted to the group with the highest level of development of technical infrastructure, while the Lubuskie Voivodeship moved from the 11th to the 8th position (an increase in the value of the synthetic indicator by 0.078), and the Łódzkie Voivodeship dropped from the 12th to the 16th position (a decrease in the value of the synthetic indicator by 0.134). The advancement of the Małopolskie Voivodeship results from the leading position in the air transport infrastructure, high position in the development of telecommunications infrastructure, and improvement of the situation in the road transport infrastructure. Lubuskie has a favorable value of the indicator in railway infrastructure and a good situation in telecommunications infrastructure. On the other hand, the significant weakening of the position of the Łódzkie Voivodeship was caused by the railway, telecommunications, and gas pollution reduction infrastructure.

In the author's opinion, the selection of regions with a similar level of technical infrastructure development can be used to research the level of social and economic development of voivodeships in Poland. The results of the analyses may form the basis for further in-depth research to determine the extent to which particular components of the technical infrastructure affect the level of its development.

The presented empirical research in the discussed area is of great significance for regional development, as they provide decision-makers with knowledge about infrastructure resources, which is used to make decisions at the national level. They can be a source of information when making decisions on the allocation of EU funds for infrastructure development in regions. The effects of investing in technical infrastructure, visible in increasing the development potential of regions and investment attractiveness, should result in the improvement of the quality of life of the local community and economic advancement of the territorial unit.

This paper aims to contribute to the considerations, in the aspect under study, in two ways. First, it provides a reliable theoretical framework for infrastructure development, including technical infrastructure. Second, it verifies empirically spatial differences in the level of technical infrastructure development in Polish regions. The assessment was made based on the characteristics accepted for research using the method of multivariate statistical analysis. The time span and the results of the research that was carried out are a strength of this study and can be used in the preparation of programs aimed at raising the level of development of technical infrastructure and its importance in the socio-economic development of the country. This thirteen-year perspective on the functioning of voivodeships has made it possible to show changes in the infrastructural facilities of Poland's regions. The availability of data limited the conducted research.

This paper highlights several areas for further research. Future research may be focused on comparing the level of infrastructure development in Poland with other European Union countries. There is also room for in-depth analyses of the impact of infrastructure on the socio-economic development in Polish regions, as it is a key factor of this development. Taking into account the fact that the conducted study covers the pre-pandemic period of COVID-19, further research may focus on a comparative analysis aimed at determining the impact of the pandemic on the development of technical infrastructure in the context of implemented infrastructure investments. This includes the development of digital infrastructure.

Faced with a turbulent present and an uncertain future, the essence, functioning, and role of infrastructure will continue to occupy a special position in the socio-economic development of regions. Based on the regional studies in the scope of solving problems related to infrastructure, it is key to answer the question of how infrastructure builds regions. It is necessary to fill the void in regional studies connected to the lack of a comparative theory of regional infrastructure (Glass *et al.,* 2019, p. 1655).

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Annex

Table 1. Variables adopted for the study of the level of technical infrastructure development in Polish regions in 2008 and 2020 — initial set

Variables	Variation coefficient	
	2008	**2020**
X_1 – Public roads with hard pavement per 100 km^2 [in km/100 km^2]	36.24	33.68
X_2 – Railway lines operated on a standard gauge per 100 km^2 [in km/100 km^2]	46.09	41.09
X_3 – Railway lines in total per 10,000 inhabitants	30.05	29.55
X_4 – Broadband Internet access in enterprises [%]	8.04	0.53
X_5 – Households with access to the Internet [%]	5.13	2.44
X_6 – Main telephone lines per 1,000 population / Subscriber lines per 1,000 population in 2020	12.78	24.11
X_7 – Population using water supply system in % of total population [%]	7.25	5.41
X_8 – Population using sewage system in % of total population [%]	14.00	11.13
X_9 – Population using gas network in % of total population [%]	24.13	22.93
X_{10} – Population using sewage treatment plants in % of total population [%]	14.01	9.47
X_{11} – Industrial and urban wastewater treated in % of wastewater requiring treatment	5.27	13.15
X_{12} – Gaseous pollutants retained in the pollutant reduction systems in % of pollutants produced [%]	63.96	43.71
X_{13} – Particulate pollutants retained in the pollutant reduction systems in % of pollutants produced [%]	0.53	0.65
X_{14} – Passenger traffic at airports [share of passenger traffic, Poland = 100]	183.48	179.72

Table 2. Selected diagnostic features concerning technical infrastructure in the years 2008 and 2020

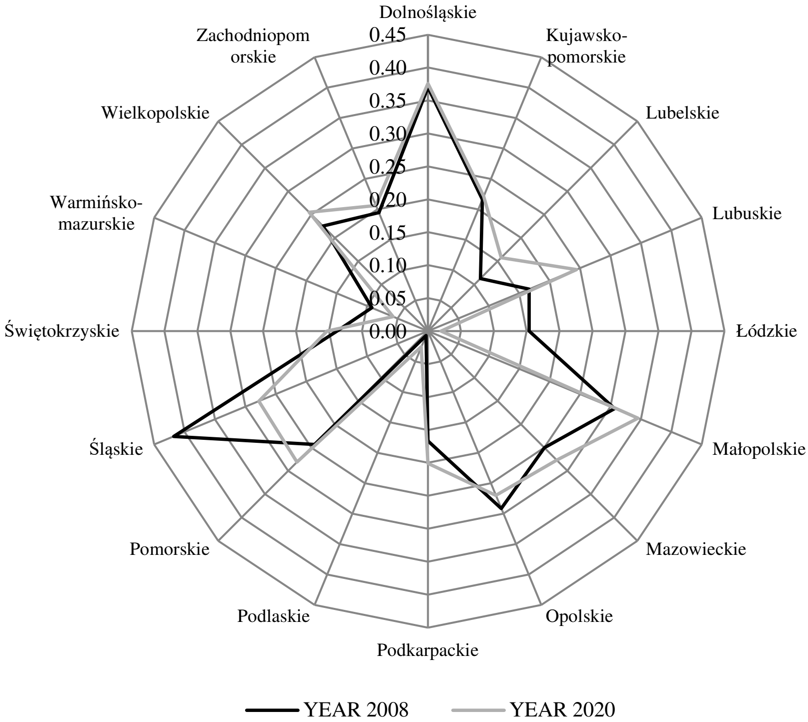
Features / Voivodeships	X_1		X_2		X_3		X_6		X_9		X_{11}		X_{12}		X_{14}	
	2008	**2020**	**2008**	**2020**	**2008**	**2020**	**2008**	**2020**	**2008**	**2020**	**2008**	**2020**	**2008**	**2020**	**2008**	**2020**
Dolnośląskie	91.5	107.0	8.8	8.7	6.1	6.0	272.0	85.0	62.4	62.6	93.21	91.3	90.4	96.1	7.1	6.9
Kujawsko-pomorskie	81.3	106.1	7.2	6.7	6.3	5.8	212.3	65.9	44.7	43.7	100.42	97.7	37.6	60.6	1.4	0.9
Lubelskie	74.9	95.0	4.1	4.3	5.0	5.2	210.9	67.1	38.2	43.8	97.29	98.6	86.6	91.5	0.0	0.8
Lubuskie	58.2	69.2	6.9	6.6	9.5	9.2	259.7	80.8	50.4	56.0	95.02	97.6	0.5	70.6	0.0	0.1
Łódzkie	94.5	116.9	5.8	5.9	4.1	4.4	234.0	62.6	39.2	40.1	92.68	59.5	62.5	88.8	1.7	0.5
Małopolskie	149.0	172.2	7.3	7.1	3.4	3.2	230.8	94.8	62.8	64.8	98.86	90.7	45.0	59.2	14.0	17.8
Mazowieckie	87.2	112.2	4.9	4.8	3.4	3.2	316.0	129.4	54.2	55.0	87.62	84.5	40.4	76.9	45.6	43.5
Opolskie	89.3	90.5	9.2	8.4	8.4	8.0	215.5	89.9	41.2	43.9	96.80	99.9	62.2	70.6	0.0	0.0
Podkarpackie	80.9	98.7	5.3	5.5	4.8	4.6	201.3	77.5	69.9	74.1	95.22	90.5	29.6	44.9	1.6	1.6
Podlaskie	56.3	70.5	3.8	3.7	6.4	6.5	237.4	67.3	26.5	29.9	99.67	99.6	5.8	30.9	0.0	0.0
Pomorskie	64.6	82.5	6.8	6.6	5.6	5.2	235.1	97.9	50.8	51.5	90.04	99.9	56.4	90.6	9.4	11.6
Śląskie	164.5	181.9	17.4	15.5	4.6	4.3	235.7	91.5	61.5	64.4	85.03	69.6	31.8	23.6	11.7	9.9
Świętokrzyskie	107.1	126.2	6.0	6.2	5.6	5.9	201.9	57.4	36.1	39.5	84.34	82.5	36.1	37.6	0.0	0.0
Warmińsko-mazurskie	51.0	59.3	5.0	4.7	8.5	8.0	202.3	62.3	43.9	42.7	95.62	99.9	2.6	3.7	0.0	0.4
Wielkopolskie	87.9	103.0	6.6	6.3	6.1	5.4	230.8	56.1	44.1	51.9	97.87	99.5	28.8	63.7	6.1	4.7
Zachodniopomorskie	57.5	63.3	5.3	5.2	7.2	7.0	240.1	80.5	58.4	61.0	93.63	99.1	43.8	69.4	1.4	1.3
Poland	83.5	100.3	6.4	6.2	5.3	5.1	241.8	85.0	51.7	54.2	92.86	86.6	54.9	70.4	100	100.0

Source: own research based on the Local Data Bank.

Table 3. Values of taxonomic measure of Polish regions technical infrastructure development by groups I-IV in 2008 and 2020

In 2008			In 2020		
No.	**Voivodeship**	***d_i* indicator**	**No.**	**Voivodeship**	***d_i* indicator**
GROUP I					
$d_i \geq 0.314$ - voivodeships with the highest level of infrastructure development			**$d_i \geq 0.316$ - voivodeships with the highest level of infrastructure development**		
1	Śląskie	0.418	1	Dolnośląskie	0.376
2	Dolnośląskie	0.370	2	Małopolskie	0.345
GROUP II					
$0.209 \leq d_i < 0.314$ - voivodeships with high level of infrastructure development			**$0.211 \leq d_i < 0.316$ - voivodeships with high level of infrastructure development**		
3	Małopolskie	0.307	3	Pomorskie	0.281
4	Opolskie	0.291	4	Śląskie	0.278
5	Mazowieckie	0.250	5	Mazowieckie	0.277
6	Pomorskie	0.243	6	Opolskie	0.270
7	Wielkopolskie	0.225	7	Wielkopolskie	0.255
8	Kujawsko-pomorskie	0.216	8	Lubuskie	0.244
			9	Kujawsko-pomorskie	0.221
GROUP III					
$0.105 \leq d_i < 0.209$ - voivodeships with low level of infrastructure development			**$0.105 \leq d_i < 0.211$ - voivodeships with high level of infrastructure development**		
9	Zachodniopomorskie	0.195	10	Zachodniopomorskie	0.206
10	Podkarpackie	0.167	11	Podkarpackie	0.201
11	Lubuskie	0.166	12	Lubelskie	0.157
12	Łódzkie	0.154	13	Świętokrzyskie	0.153
13	Świętokrzyskie	0.138			
14	Lubelskie	0.113			
GROUP IV					
$d_i < 0.105$ - voivodeships with very low level of infrastructure development			**$d_i < 0.105$ - voivodeships with very low level of infrastructure development**		
15	Warmińsko-mazurskie	0.092	14	Warmińsko-mazurskie	0.057
16	Podlaskie	0.007	15	Podlaskie	0.026
			16	Łódzkie	0.020

Figure 1. Distance of Polish regions from the development pattern in 2008 and 2020



Source: own research based on data from Table 3.