Sustainable development in Poland in quantitative terms – state as of 2022

Kacper Zielak,[a] Helena Gaspars-Wieloch[b]

Abstract. Sustainable development remains one of the major challenges for contemporary Poland, where dynamic economic growth often collides with social inequalities and environmental degradation. In relation to these challenges, this paper aims to assess the level of sustainable development in voivodships (highest-level administrative division of Poland, equivalent to a province) based on an extended analytical framework that adds an institutional-political dimension to the three core aspects of sustainable development – social, economic and environmental. The study relies on data from 2022 on individual voivodships, from which 20 variables describing the aforementioned aspects of sustainable development are selected. In the extended approach, these aspects are often referred to as 'orders'. For each voivodship, Hellwig's measure is calculated using multidimensional comparative analysis and linear ordering. Based on these calculations, rankings of Polish voivodships are created and visualised by means of cartograms created in R. Additionally, an analysis of the similarity of objects relative to each other is conducted using Euclidean distance matrices. The research shows, among other aspects, which orders of sustainable development constitute the strengths and which represent weaknesses of a given voivodship. The study refers to literature discussing the concept of sustainable development and methods of quantifying it, as well as literature describing the applied research methodology.
Keywords: sustainable development, Hellwig's measure multidimensional analysis, linear ordering, distance matrix, rankings of Polish voivodships
JEL: C44, Q01, Q5, R5

1. Introduction

Sustainable development is a concept appearing increasingly often in public discourse. Major global organisations such as the United Nations and the European Union, as well as the media, strive to raise public awareness of sustainable development, which is regarded by highly developed countries as the primary direction of development for the future. Nevertheless,

[a] Poznan University of Economics and Business, Department of Operations Research and Mathematical Economics, Poland, al. Niepodległości 10, 61-875 Poznań, Poland, e-mail: kacper.zielak@ue.poznan.pl, ORCID: https://orcid.org/0009-0002-6098-9095.
[b] Poznan University of Economics and Business, Department of Operations Research and Mathematical Economics, al. Niepodległości 10, 61-875 Poznań, Poland, e-mail: helena.gaspars@ue.poznan.pl, ORCID: https://orcid.org/0000-0003-0033-3836.

achieving sustainable development remains a complex challenge, influenced by factors such as political instability, administrative inefficiency, resource limitations, social and economic disparities across regions and possibly a still insufficient level of self-awareness among a large segment of the population regarding sustainable development. Recognising these limitations highlights the need for continuous, multidimensional research and adaptive policy-making. The analysis of sustainable development can be seen as an extension of quality-of-life studies, as it goes beyond the socio-economic aspects commonly used in such research to include other, less obvious dimensions. Consequently, this approach offers a broader perspective on the issue and enables the formulation of more complex conclusions.

The aim of the paper is to evaluate the level of sustainable development across Polish voivodships by incorporating the institutional-political dimension alongside the commonly recognised social, economic and environmental ones. The inclusion of this additional dimension plays a crucial role as it complements the three main aspects and thus offers a broader, more holistic view of sustainable development. For example, a well-trained and non-corrupt administration, supported by non-profit organisations can contribute to making more rational decisions regarding environmental protection (including the management of natural resources), improving economic indicators (for instance, investments are carried out more efficiently when legal regulations and administration support economic activity) and enhancing the situation of the society (e.g. well-educated officials can improve road safety). It is also worth mentioning that in this context, ‘dimensions’ are often referred to as ‘orders’ of sustainable development.

Sustainable development, as one of the most popular development concepts, has been widely accepted, at least at the level of general formulations and assumptions. This concept is described as an attempt to holistically integrate humanity, the environment and the economy, standing in opposition to the traditional approach that treats these three categories as separate (Buchard-Dziubińska et al., 2014). The notion of sustainable development is also described as a response to the increasing concerns about the burden placed on our planet’s ecosystems and caused by anthropogenic factors. This response takes the form of a strategy aimed at eliminating or reducing the imbalance that may arise between economic and social development, as well as between socio-economic development and the natural environment (Poskrobko, 2009). It is also said that sustainable development most often appears in two contexts. The first is the discussion about development goals and the tools to achieve them. The second context is the perception of sustainable development as a relationship between humans and the environment, which must be shaped according to new principles (Trzepacz, 2012). All of the perspectives above boil down to the assumption that humans, as leaders of civilizational (including economic) development, are obligated to strive for a particular harmony with the natural environment.

As regards the formal definition of sustainable development, the most popular one was formulated in 1987 in a report titled *Our Common Future* (also known as the *Brundtland Report*), prepared by the World Commission on Environment and Development. In this report, we read: 'Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations Secretary-General. World Commission on Environment and Development, 1987). Analysing the cited definition, we may conclude that acting in accordance with sustainable development means seeking a vision of civilisation that continuously 'satisfies' humanity while simultaneously caring for the well-being of future generations.

The literature shows that there are several ways that sustainable development may be perceived. One of the basic approaches involves distinguishing its three fundamental dimensions: social, economic and ecological (Atkinson et al., 2014; Baum, 2021; Gupta & Vegelin, 2016; Ilić Krstić et al., 2018; Islam, 2025; Mensah, 2019; Stec et al., 2024). These are interrelated dimensions, with the human at the centre, striving to maintain a balance between them. This perspective is often visualised by means of a Venn diagram, consisting of three circles corresponding to the individual dimensions.

The concept above serves as a starting point for more advanced, comprehensive analyses of sustainable development, where accounting for additional dimensions influencing sustainability often poses a significant challenge. However, this approach may contribute to fulfilling an existing research gap. One of these analyses additionally includes the spatial dimension, according to which development should be characterised by rational methods of land and space use. The human task is to consciously organise their environment, both natural and anthropogenic. Examples of such actions include ensuring proper policies related to nature protection, as well as maintaining appropriate hygiene and cleanliness in areas inhabited by humans, particularly in cities. It is important to emphasise that this approach to sustainable development treats land as a particularly valuable resource due to its limited character and non-reproducibility in production processes (Buchard-Dziubińska et al., 2014).

Another expanded perspective on sustainable development, which this paper is based on, involves highlighting an additional, fourth dimension known as the institutional-political dimension. As mentioned before, in this framework, the dimensions are often called 'orders' of sustainable development. Their mutual integration and maintaining proper balance between them aim to improve the broadly understood quality of life for present and future generations. In practice, these orders are associated with the following actions:

- social order – combating poverty, fostering cultural development and meeting fundamental human needs, such as access to healthcare and education;
- economic order – pursuing economic growth that ensures a sufficient supply of goods and services and increasing market innovation;
- environmental order – developing solutions to reduce the consumption of natural resources, protecting the environment from further degradation and raising public awareness of ecological issues;
- institutional-political order – shaping efficient and strong public institutions, providing citizens with access to justice and promoting an inclusive society (Drabarczyk, 2017).

When discussing sustainable development from the perspective of the four orders, it is important to precisely define the concept of order. According to Sztumski (2006, p. 74), 'It is an organisation of a system that enables the harmonious functioning of its elements in such a way that the system as a whole can effectively fulfil its purpose and carry out the tasks for which it is intended'. A conventional division of the system into parts can correspond to the individual orders of sustainable development, depending on the specific domain.

The result of sustainable development is the achievement of an 'integrated order'. This is interpreted as a target state that ensures the cohesive and simultaneous attainment of the four specified orders (Balas & Molenda, 2016). In Borys (2011), we can read that 'Integrated order is the target state of sustainable development, a reference point for developmental changes characterized by the quality of sustainability. This implies that sustainable development cannot be equated with integrated order because the first one is a process, and the second one is the target state of developmental changes'. As a result, achieving all orders simultaneously guarantees entry onto the path of sustainable development, which is considered as a (potentially long-term) process. Remaining on this path, in turn, enables the establishment of certain developmental patterns, which collectively contribute to the formation of an integrated order.

The remaining part of this paper is organised as follows. Section 2 describes the methods used to conduct the study, along with their main assumptions and the applied formulas. This section is also dedicated to the 20 variables used in the study. Section 3 presents a multidimensional comparative analysis which contains all necessary calculations for the construction of rankings and classifications aiming to quantify sustainable development in each voivodship. Finally, in Section 4 the study results are summarised and interpreted.

2. Methodology

In this paper, an attempt is made to quantify sustainable development based on multidimensional comparative analysis. This notion is associated with a group of mathematical methods used to analyse objects in terms of certain complex phenomena that require multiple (at least two) variables for their characterisation. The term 'object' refers to the examined units subject to classification or grouping (Ulmann, 2020). Referring to the part of the previous chapter, the extended concept of sustainable development boils down to distinguishing its four main dimensions called orders (social, economic, environmental and institutional-political). To conduct a multidimensional comparative analysis, the individual orders must be associated with specific sets of objects and variables that describe these objects. Due to the chosen topic, the set of objects is formed by voivodships in Poland. The variables are divided into four equal groups corresponding to the different dimensions of sustainable development. All characteristics pertain to the year 2022, and their selection is based on the report of the Statistical Office in Katowice titled *Wskaźniki zrównoważonego rozwoju Polski* (Urząd Statystyczny w Katowicach, 2015). Although the aforementioned report includes a broad set of variables (e.g. public expenditure on education as a percentage of GDP or energy intensity of the economy), not all of them are suitable for regional-level analysis due to the lack of complete or comparable data across voivodships. Owing to the extensive number of indicators presented in the report, a more selective approach is adopted in this study. The variables are selected to ensure diversity and to represent various aspects of each of the examined dimensions – social, economic, environmental and institutional-political. This approach allows maintaining a balance between comprehensiveness and clarity. The data sources include Statistics Poland, Office of Rail Transport (Urząd Transportu Kolejowego) and the Polish National Police Portal (Portal Polskiej Policji).

The study applies methods such as Hellwig's measure of development and distance matrix construction. The first one is a well-known multi-objective procedure used in various fields such as banking or social sciences due to its ability to assess and compare objects based on multiple criteria. Hellwig's method has also undergone various modifications presented in Roszkowska (2024) and Roszkowska et al. (2024). Other methods are also commonly applied in the multidimensional analysis of sustainable development, such as TOPSIS, weighted sum and ELECTRE (Lindfors, 2021). The choice of Hellwig's method is guided by its computational simplicity and clarity of interpretation. Unlike TOPSIS, it does not require the identification of an anti-pattern, which reduces the complexity of the procedure. It is important to underline that each method is based on different assumptions. While both Hellwig's measure and TOPSIS rely on reference points, ELECTRE operates on an outranking relation, which makes direct comparisons between such techniques challenging. The selection of a method therefore depends on the preferences of the decision-maker and the purpose of the analysis. For instance, if the goal is to create a ranking relative to reference values, pattern-based methods like Hellwig's measure are appropriate. On the other hand, if the analyst questions the influence of extreme reference values, methods such as ELECTRE may be more suitable.

In general, the set of objects studied in relation to a certain complex phenomenon can be represented as:

$$\Omega = \{O_1, O_2, O_3, \dots, O_N\}, \tag{1}$$

where $O_1, O_2, O_3, \dots, O_N$ describe objects examined due to some complex phenomenon and N represents the total number of objects in the study.

The set of variables (sustainable development indicators) can be expressed as:

$$X = \{X_1, X_2, X_3, \dots, X_K\}, \tag{2}$$

where $X_1, X_2, X_3, \dots, X_K$ indicate variables describing the objects and K is the total number of variables.

The objects and variables defined in this way form an observation matrix (realisations of variables) with dimensions $N \times K$ in the following form:

$$X_{N\times K} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1K} \\ x_{21} & x_{22} & \cdots & x_{2K} \\ \cdots & \cdots & \cdots & \cdots \\ x_{N1} & x_{N2} & \cdots & x_{NK} \end{bmatrix}, \tag{3}$$

where x_{ik} denotes the value of the k-th variable for the i-th object ($i = 1, \dots, N;\ k = 1, \dots, K$).

Based on matrix $X_{N\times K}$, the following procedure is applied to calculate Hellwig's measure of development:

1. Identification of the nature of the variables (divided into stimulants, destimulants, nominants);
2. Unifying the nature of the variables (bringing the variables into the form of stimulants);
3. Normalisation of units and scales of variables through unitarisation using the following formula:

$$z_{ik} = \frac{x_{ik} - x_k^{min}}{x_k^{max} - x_k^{min}}, \tag{4}$$

where x_k^{max} (x_k^{min}) denotes the maximum (minimum) value of the k-th variable and z_{ik} represents the normalised value of the k-th variable for the i-th object, corresponding to value x_{ik}. Normalisation can also be performed in other ways. Example formulas can be found in studies such as Gaspars-Wieloch (2012), Roszkowska (2011) and Vafaei et al. (2018), but the normalisation procedure applied in this research is quite universal, as it can be used for both positive and negative data. Moreover, it allows assigning a zero value to the worst object in the group and a unit value to the best object.

The choice of any normalisation technique affects the scaling of the variables, which, in turn, impacts the synthetic measure. In the case of unitarisation, the main factor determining the normalised value is outliers recorded for a given variable. Therefore, if these values differ significantly from the intermediate values, the results obtained through unitarisation may not be fully useful when determining the synthetic measure. This issue does not occur with other methods, such as standardisation. In this study, the authors conduct a statistical analysis of the source data (available in the following link: https://docs.google.com/spreadsheets/d/1W5vt9DYqITRxGaoaCd18DJzJ7Qn9F7Wb/edit?usp=sharing&ouid=116594861186276178752&rtpof=true&sd=true) and conclude that, although some variables exhibit significant asymmetric outliers, unitarisation remains a justified choice due to its widespread use in the literature (Kukuła & Bogocz, 2014; Leń et al., 2016; Radzka et al., 2015). Nevertheless, in cases of excessive asymmetry, this issue can be addressed by applying alternative techniques that limit the influence of extreme values in statistical data (Łuczak et al., 2025; Łuczak & Just, 2020a, 2020b; Łuczak & Just, 2021). Hence, future research could compare the results with those derived from other normalisation methods in order to assess the stability of the results.

The result of the transformation is a matrix of a normalised observation:

$$Z_{N\times K} = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1K} \\ z_{21} & z_{22} & \cdots & z_{2K} \\ \cdots & \cdots & \cdots & \cdots \\ z_{N1} & z_{N2} & \cdots & z_{NK} \end{bmatrix}. \tag{5}$$

4. Finding the pattern in the cross-section of each variable according to the following formula:

$$z_0 = [z_{01} \dots z_{0K}], \quad \text{where} \quad z_{0k} = \max_i (z_{ik}); \tag{6}$$

5. Calculating the distance between the i-th object and the pattern:

$$d_i = \sqrt{\sum_{k=1}^{K} (z_{0k} - z_{ik})^2}; \tag{7}$$

Higher values of d_i indicate a lower similarity of the i-th object to the hypothetical pattern.

6. Calculating the values of Hellwig's measure of development. For the i-th object, we compute:

$$H_i = 1 - \frac{d_i}{d_0}, \tag{8}$$

where $d_0 = \overline{d} + 2s_d$, for $\overline{d} = \frac{1}{N}\sum_{i=1}^{N} d_i$, $s_d = \sqrt{\frac{1}{N-1}(d_i - \overline{d})^2}$.

The highest possible value of Hellwig's measure is one, which represents an extreme case where the i-th object corresponds to the ideal object, where it is identical to the pattern. Smaller values of the measure indicate a worse realisation of the studied complex phenomenon. If there are objects in the data set that are significantly worse and deviate from the others, the measure can take values below zero (Appenzeller & Jurek, 2018).

7. Ranking of the objects according to descending H_i.

8. Classification of objects into classes based on the value of Hellwig's measure. To facilitate interpretation, the following additional notation is introduced:

   $\overline{H}$ – the average value of Hellwig's measure in the set of the analysed objects,

   s_H – the standard deviation of Hellwig's measure in the set of the analysed objects.

The classification rules are presented in Table 1:

Table 1. Classification of objects based on the value of Hellwig's measure

Two-class	Three-class	Four-class
Above average	Good	Very good

$H_i > \overline{H}$	$H_i > \overline{H} + s_H$	$H_i > \overline{H} + s_H$
Below average $H_i \leq \overline{H}$	Average $\overline{H} - s_H \leq H_i \leq \overline{H} + s_H$	Good $\overline{H} < H_i \leq \overline{H} + s_H$
	Poor $H_i < \overline{H} - s_H$	Average $\overline{H} - s_H < H_i \leq \overline{H}$
		Poor $H_i \leq \overline{H} - s_H$

Source: Appenzeller and Jurek (2018).

In the present analysis, a four-class division is applied.

9. Calculating the Sustainable Development Index (SDI) as the arithmetic mean of Hellwig's measure values for each order, assuming equal importance for all dimensions. This provides a single aggregated value for each voivodship;

10. Repeating the ranking and classification procedure based on SDI values.

The next step of the study involves calculating the distance matrix, which allows for the examination of the similarity between objects. The distance between the i-th object and j-th object satisfies four conditions: non-negativity, symmetry, reflexivity and triangle inequality. To calculate the discussed distances, one of the most basic measures, the Euclidean distance, given by (9), is used:

$$d_{ij} = \sqrt{\sum_{k=1}^{K}(z_{ik} - z_{jk})^2}, \tag{9}$$

where z_{ik} and z_{jk} denote the normalised values corresponding to observations x_{ik} and x_{jk}. The distances calculated in this way include all pairs of objects. The minimum value of the matrix (excluding the main diagonal, where values are zero due to the symmetry condition) identifies the pair of objects that are the most similar, while the maximum value indicates the pair of objects that are the most different.

According to the extended concept of sustainable development, the four main dimensions (orders), are distinguished: social, economic, environmental and institutional-political. This conceptual framework guides the selection of diagnostic variables used in the empirical study. As a result, 20 variables are selected and equally divided among the four orders, with five indicators assigned to each. This approach aligns with the fundamental idea of sustainable development, which emphasises the balanced and harmonious advancement of all orders. While this symmetrical structure highlights the equal importance of each order, the selection of variables is not random. Only indicators that demonstrate sufficient variability and low mutual correlation are included. To enhance the information value of the indicators, only variables with a coefficient of variation of at least 10% are considered. Although Appenzeller and Jurek (2018) recommend a higher threshold of around 20%, the authors lowered it due to data availability constraints.

The first five variables used in the study, i.e., $X_1, \dots, X_5$, are assigned to the social order. Their names and types (stimulant, destimulant, nominant) are presented in Table 2 below.

Table 2. Indicators connected with the social order

Indicator	Name	Type
X_1	At-risk-of-poverty rate after considering social transfers in income	Destimulant
X_2	Road traffic fatalities per 100,000 population	Destimulant
X_3	Number of housing units put into use per 1,000 population aged 25–34	Stimulant
X_4	Share of adults participating in education or training aged 25–64	Stimulant
X_5	Number of doctors (personnel working in total) per 10,000 population	Stimulant

Source: authors' work.

The next group of variables pertains to the economic order of sustainable development. This group consists of variables $X_6, \dots, X_{10}$, which are presented in Table 3.

Table 3. Indicators connected with the economic order

Indicator	Name	Type
X_6	Labour productivity in the industrial sector	Stimulant
X_7	Voivodships budget revenues *per capita*	Stimulant
X_8	Share of railway lines adapted for speeds of 120 km/h and above in the total length of operational railway lines	Stimulant
X_9	Registered unemployment rate	Destimulant
X_{10}	Investment expenditures *per capita*	Stimulant

Source: authors' work.

Variables $X_{11}, \dots, X_{15}$ used in the study cover the environmental order. Their description is provided in Table 4.

Table 4. Indicators connected with the environmental order

Indicator	Name	Type
X_{11}	Share of renewable energy in total electricity production	Stimulant
X_{12}	Forest cover	Stimulant
X_{13}	Annual water consumption *per capita*	Destimulant
X_{14}	Municipal waste generated *per capita*	Destimulant
X_{15}	Share of legally protected areas in the total area	Stimulant

Source: authors' work.

The last order of sustainable development called institutional-political is described using variables $X_{16}, \dots, X_{20}$ (Table 5).

Table 5. Indicators connected with the institutional-political order

Indicator	Name	Type

X_{16}	Share of public administration units providing training for employees in telecommunications and information technology	Stimulant
X_{17}	Number of active non-profit organisations per 10,000 population	Stimulant
X_{18}	Number of corruption crimes per 100,000 population	Destimulant
X_{19}	Number of public administration employees per 10,000 population	Nominant
X_{20}	Share of women in the legislative bodies of local government units	Nominant

Source: authors' work.

3. Results

Using formula (8), the values of Hellwig's measure were calculated for each voivodship across the four orders of sustainable development. These values are presented in Table 6. Based on these values, as well as their descriptive statistics such as mean and standard deviation, rankings of voivodships were created. The objects in the rankings were divided into four groups: very good, good, average and poor. Each group reflects the qualitative level of the studied complex phenomenon. Due to the fact that the calculated aggregate variables are stimulants, voivodships characterised by higher values of Hellwig's measure occupy higher positions in the rankings. The visualisation of the analysis results is presented in Cartograms 1–4.

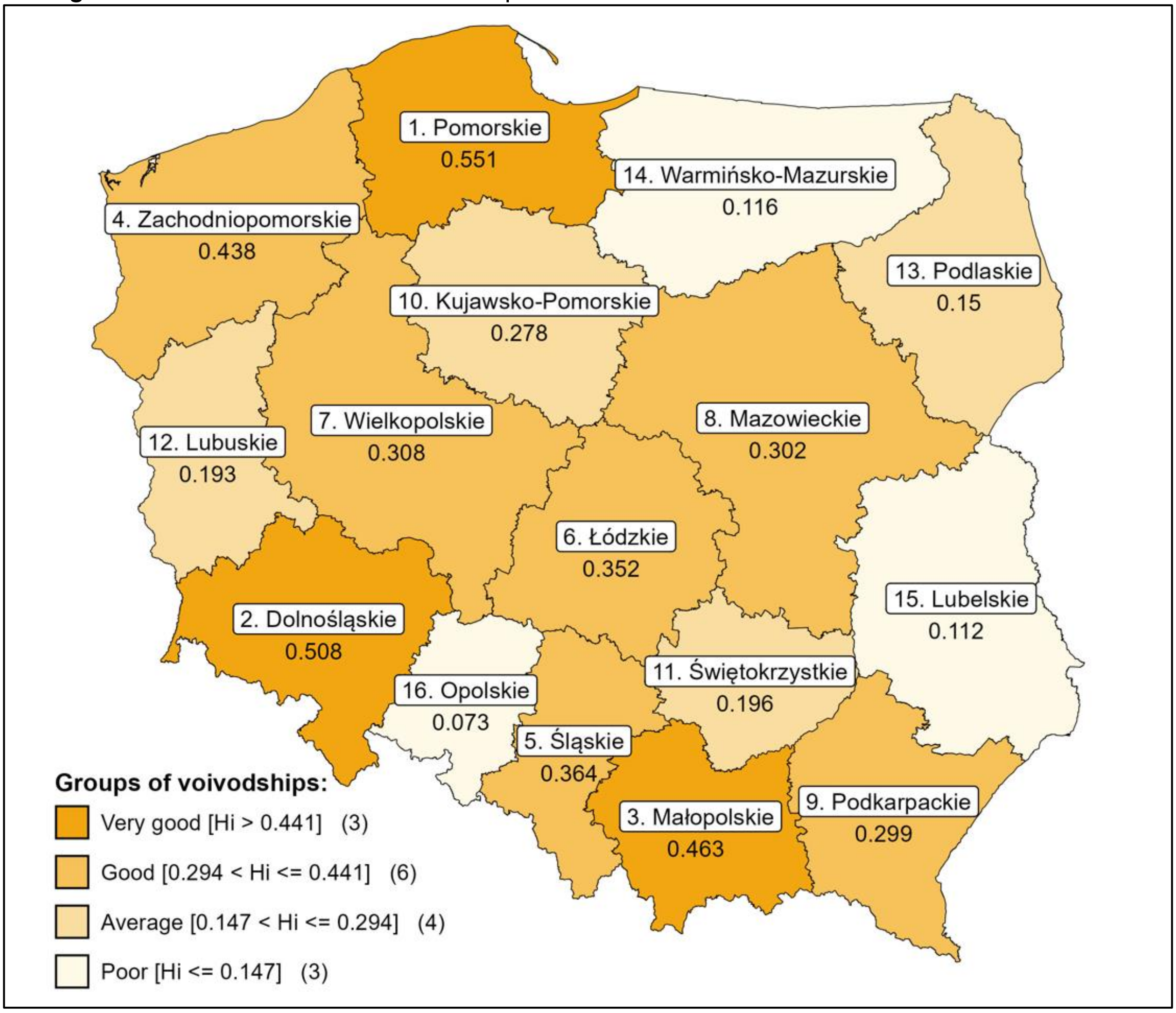
Table 6. Values of Hellwig's measure for individual voivodships

Voivodship	Social order	Economic order	Environmental order	Institutional-political order
Dolnośląskie	0.508	0.475	0.144	0.303
Kujawsko-Pomorskie	0.278	0.341	0.319	0.555
Lubelskie	0.112	0.226	0.331	0.235
Lubuskie	0.193	0.408	0.420	0.407
Łódzkie	0.352	0.330	0.135	0.279
Małopolskie	0.463	0.380	0.377	0.309
Mazowieckie	0.302	0.890	0.114	0.094
Opolskie	0.073	0.348	0.184	0.348
Podkarpackie	0.299	0.154	0.633	0.091
Podlaskie	0.150	0.227	0.514	0.049
Pomorskie	0.551	0.369	0.433	0.341
Śląskie	0.364	0.290	0.217	0.120
Świętokrzyskie	0.196	0.172	0.308	0.220
Warmińsko-Mazurskie	0.116	0.169	0.577	0.403
Wielkopolskie	0.308	0.459	0.220	0.415
Zachodniopomorskie	0.438	0.374	0.211	0.274

Source: authors' work.

In the case of the social order (Cartogram voivodships performed the most poorly. The group described as 'good' consists of six voivodships and forms the largest one. Based on the geographical location of the objects, it can be observed that voivodships with relatively higher values of Hellwig's measure are situated in north-western, central and southern Poland (excluding Opolskie Voivodship, which was mentioned before). In contrast, in the eastern part of the country, voivodships represent the social order of sustainable development less favourably. The range of this index is 0.478.

Cartogram 1. Social order across voivodships

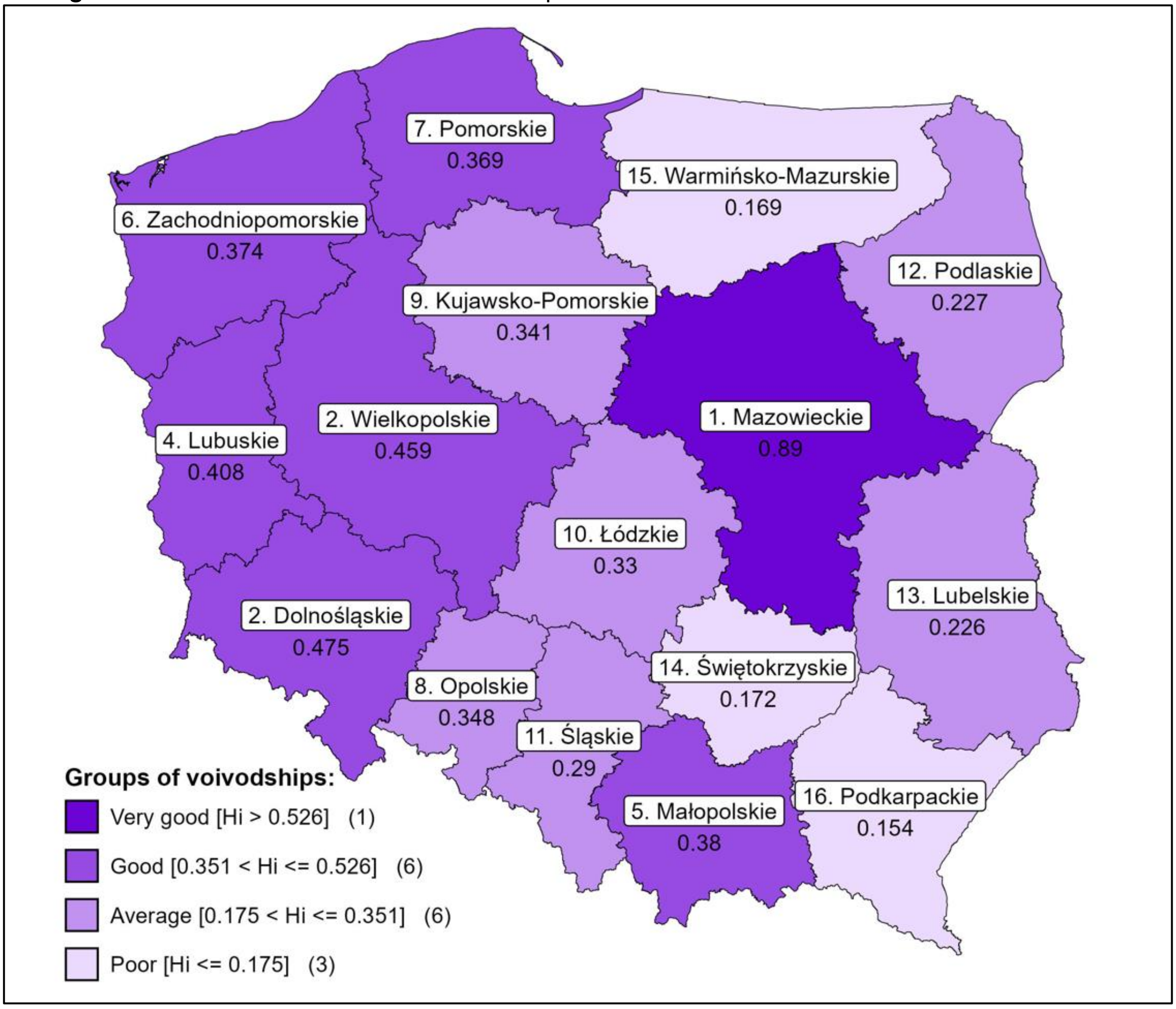


Source: authors' work.

Analysing the values of Hellwig's measure in the context of economic order, as shown on Cartogram 2, a significant dominance of Mazowieckie Voivodship over other regions is evident. This voivodship is the only one classified in the 'very good' group, achieving an aggregate variable of 0.89, which is close to the pattern. Additionally, it borders only with voivodships classified as 'average' and 'poor'. Moreover, the 'good' group, excluding Małopolskie

Voivodship, is predominantly located in the western part of the country. The range of Hellwig's measure for this order equals 0.735, which is more than twice the average value, due to the outlier value of Mazowieckie Voivodship.

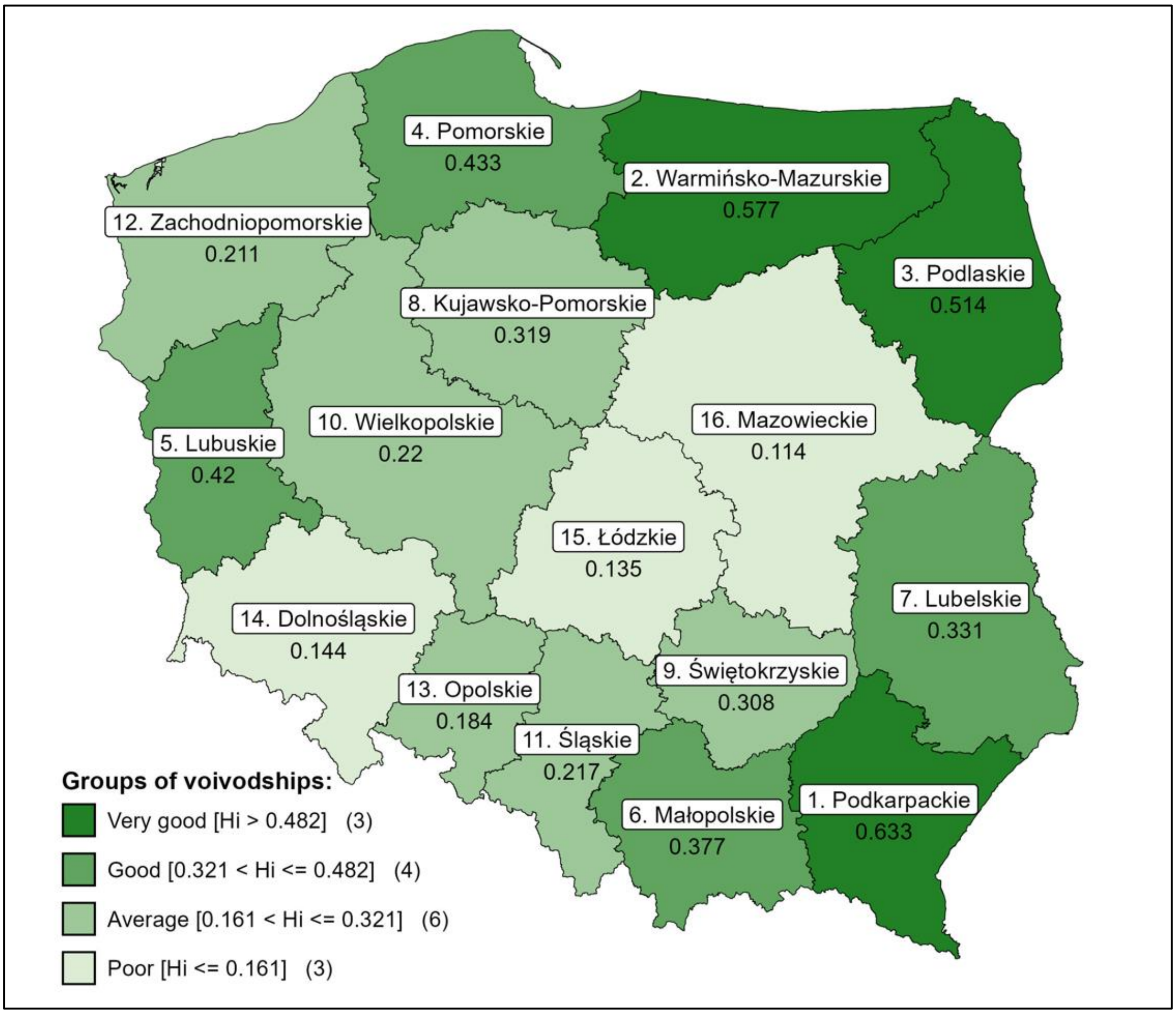
Cartogram 2. Economic order across voivodships



Source: authors' work.

Cartogram 3 reveals a clear regional differentiation of voivodships in terms of the environmental order of sustainable development. In the northern and south-eastern parts of the country, voivodships occupy the top half positions of the constructed ranking. This is likely due to the lower degree of industrialisation in these regions, which helps to maintain high ecological value. In contrast, there is a predominance of 'average' and 'poor' voivodships in central and south-western Poland. The 'very good' and 'poor' groups each consist of three voivodships. The 'very good' group includes Podkarpackie, Warmińsko-Mazurskie and Podlaskie voivodships. Meanwhile, Dolnośląskie, Łódzkie and Mazowieckie voivodships form the 'poor' group. The difference between the maximum and minimum values of the aggregate variable is 0.519.

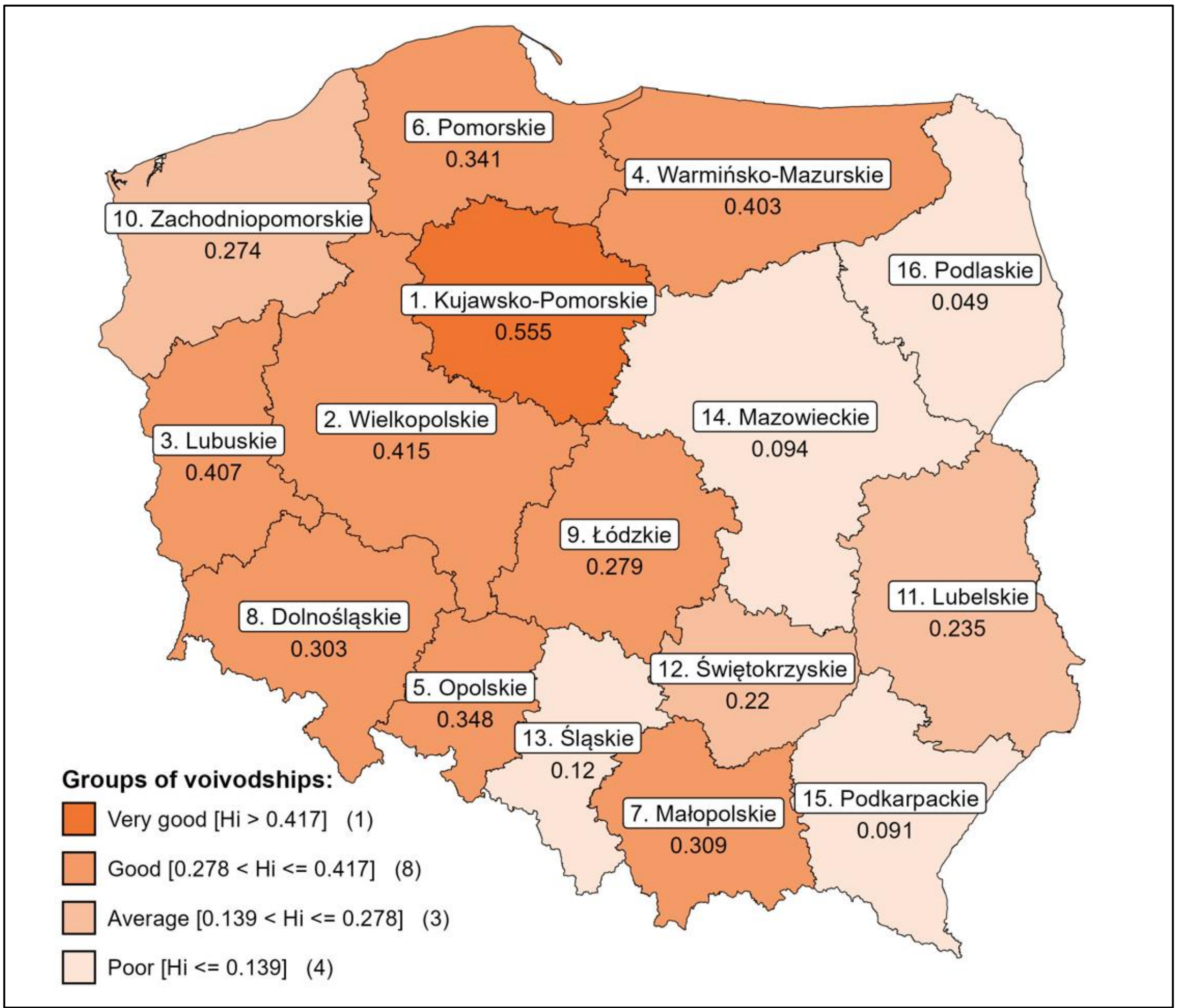
Cartogram 3. Environmental order across voivodships



Source: authors' work.

As regards the institutional-political order of sustainable development (Cartogram 4), voivodships located in the south-western and northern parts of Poland exhibit higher values of the index. Conversely, lower values are observed in the eastern part of the country. Similarly to the economic order, the 'very good' group consists of only one voivodship; however, this time, it is Kujawsko-Pomorskie Voivodship. The largest group is the one described as 'good', created by eight voivodships, representing half of all the objects. The range of the index values for this order is 0.506.

Cartogram 4. Institutional-political order across voivodships



Source: authors' work.

In the next step, we attempt to achieve the highest level of aggregation by creating an index that characterises the level of sustainable development in each voivodship with a single value. Assuming that each order has an equal impact on sustainable development and using the previously calculated Hellwig's measure values, the SDI is determined. From a mathematical perspective, this means that each order is assigned an equal weight, reducing the weighted average to an arithmetic mean. The SDI values are presented in Table 7. The voivodships are again divided into groups and a ranking is established.

Table 7. SDI values for individual voivodships

Voivodship	Sustainable Development Index
Dolnośląskie	0.358
Kujawsko-Pomorskie	0.373
Lubelskie	0.226
Lubuskie	0.357

Łódzkie	0.274
Małopolskie	0.382
Mazowieckie	0.350
Opolskie	0.238
Podkarpackie	0.295
Podlaskie	0.235
Pomorskie	0.423
Śląskie	0.248
Świętokrzyskie	0.224
Warmińsko-Mazurskie	0.316
Wielkopolskie	0.351
Zachodniopomorskie	0.325

Source: authors' work.

Cartogram 5 illustrates that the four classes of voivodships, founded on SDI values, exhibit a certain degree of spatial coherence, forming distinct clusters. Below is a description of each class in detail:

a) Very good – this class is an exception, consisting of only two voivodships located on opposite sides of Poland: Pomorskie and Małopolskie. Notably, Pomorskie Voivodship borders only with voivodships from the 'good' group, whereas Małopolskie Voivodship is surrounded exclusively by 'average' and 'poor' voivodships. This is also the smallest class in this classification.

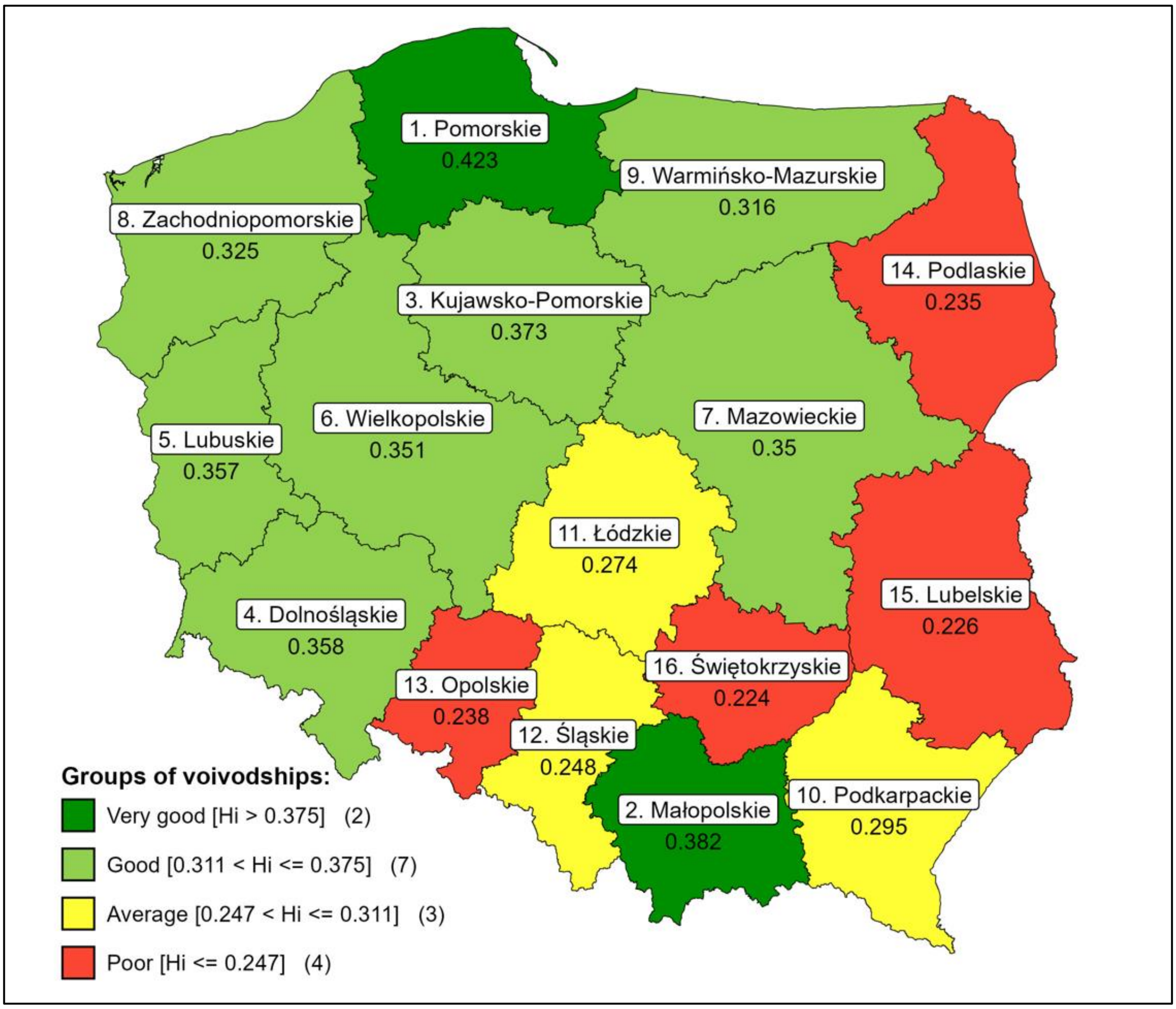
b) Good – the largest group among the analysed classes, comprising seven voivodships: Kujawsko-Pomorskie, Dolnośląskie, Lubuskie, Wielkopolskie, Mazowieckie, Zachodniopomorskie and Warmińsko-Mazurskie. This group covers nearly half of Poland's territory, predominantly extending across the northern and western regions.

c) Average – this class includes voivodships located in central and southern Poland: Podkarpackie, Łódzkie and Śląskie.

d) Poor – consisting of four voivodships: Opolskie, Podlaskie, Lubelskie and Świętokrzyskie. These objects are mostly situated in the eastern part of the country (Opolskie Voivodship is an exception), demonstrating the lowest level of sustainable development in the analysis.

It is also worth noting that the SDI has the smallest range among all the discussed indicators, which is around 0.2. This is due to the fact that the SDI, as an attempt at the highest level of aggregation, is based on averaged values.

Cartogram 5. The level of sustainable development across voivodships



Source: authors' work.

The analysis of the differentiation of voivodships for individual orders of sustainable development, which involves constructing a distance matrix, requires transforming all variables into stimulants and normalising their values. After that, using formula (9), Euclidean distances d_{ij} are calculated for each pair of voivodships. The results of the calculations are presented in the table below.

Table 8. Euclidean distances between voivodships – summary across four orders of sustainable development

Order	**Most similar voivodships**	**Value of d_{ij}**	**Most different voivodships**	**Value of d_{ij}**
Social	Lubelskie Podlaskie	0.218	Mazowieckie Warmińsko-Mazurskie	1.599

Economic	Lubuskie Małopolskie	0.230	Mazowieckie Podkaprackie	1.699
Environmental	Dolnośląskie Opolskie	0.272	Lubuskie Świętokrzyskie	1.513
Institutional-political	Lubelskie Świętokrzyskie	0.165	Kujawsko-Pomorskie Mazowieckie	1.439

Source: author's work.

Mazowieckie Voivodship appears among the most different pairs in three out of the four analysed categories. In contrast, Lubelskie Voivodship is part of the most similar pairs in the social and institutional-political orders. Lubuskie and Świętokrzyskie Voivodships are also noteworthy, as they belong to both the most similar and the most dissimilar pairs. This highlights the multidimensional nature of sustainable development – a region may be similar to others in one area while significantly differing in another. Overall, the differences in Euclidean distances between voivodships may reflect their regional specificities, which provides a valuable source of information for further research or more targeted, thematically differentiated regional policy interventions.

4. Conclusions

Below is a summary of our findings and the main conclusions formulated on the basis of our research results:

- Due to the economic and institutional-political orders, the voivodships located in the western part of the country exhibit relatively higher values of Hellwig's measure. It is important to emphasise that the economic order, in addition to the economic sphere, also includes such aspects as transport and labour productivity;
- Voivodships considered better in terms of the environmental order predominate in the northern and eastern regions of Poland;
- Mazowieckie and Podkarpackie voivodships serve as examples of regions that rank both at the top and bottom of the created rankings, depending on the analysed order of sustainable development. This may indicate problems in implementing a coherent policy in these areas;
- In the case of the SDI, some classes of voivodships form geographically homogeneous groups. This points to a certain disparity in the level of sustainable development, suggesting the need to determine the exact causes of these differences and take relevant action to reduce

their effects. This applies primarily to the region covering parts of central, southern and eastern Poland;

- Individual distance matrices correspond to the created rankings, as, on average, the most similar pairs of voivodships occupy similar, often adjacent ranking positions. Conversely, the most dissimilar pairs of voivodships tend to have relatively more distant or even extreme ranking positions, as exemplified by Mazowieckie and Podkarpackie voivodships in the context of economic order. It should be noted that this is not always the case, as ‘different’ does not necessarily mean ‘worse’;
- An advantage of the conducted research is the addition of a fourth order (institutional-political), which allows for a broader perspective on sustainable development;
- The study is characterised by objectivity due to equal weights assigned to individual orders of sustainable development, an identical number of variables for each order and equivalent weights for all criteria within each dimension;
- In similar research, differentiated weights may be applied based on the coefficients of variation or determined through expert surveys to identify the most influential indicators of sustainable development;
- It is important to consider that in a similar study, all ranking positions and, consequently, the conclusions drawn in the above points may change. Factors influencing these changes may include the selection of a different set of variables (which could be beneficial or detrimental for certain voivodships), assigning different weights to each order of sustainable development (if such an approach is considered), analysing different time periods and choosing a different calculation method, e.g. TOPSIS;
- The conducted analysis or similar studies can be expanded by incorporating the aspect of spatial autocorrelation or using the Extended Hellwig Method (Roszkowska & Filipowicz-Chomko, 2021), or applying a wider set of variables if data availability permits or if new challenges in regional sustainable development emerge;
- A further direction of research could involve monitoring the situation related to sustainable development in Poland during the implementation of the goals outlined in the 2030 Agenda, as well as after their achievement, and comparing the results from different study periods.

References

Appenzeller, D., & Jurek, W. (2018). *Podstawy ekonometrii i badań operacyjnych. Zastosowania w ekonomii i zarządzaniu.* Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu.

Atkinson, G., Dietz, S., Neumayer, E., & Agarwala, M. (Eds.). (2014). *Handbook of Sustainable Development* (2nd edition). Edward Elgar Publishing.

Balas, A., & Molenda, A. (2016). Koncepcja doboru wskaźników zrównoważonego rozwoju Polski oraz narzędzie ich udostępniania i prezentacji. *Optimum. Studia Ekonomiczne*, (2), 97–114. https://doi.org/10.15290/ose.2016.02.80.08.

Baum, R. (2021). Sustainable development – a modern understanding of the concept. *Annals of the Polish Association of Agricultural and Agribusiness Economists*, *23*(2), 9–29. https://doi.org/10.5604/01.3001.0015.0026.

Borys, T. (2011). Zrównoważony rozwój – jak rozpoznać ład zintegrowany. *Problemy Ekorozwoju*, *6*(2), 75–81.

Buchard-Dziubińska, M., Rzeńca, A., & Drzazga, D. (2014). *Zrównoważony rozwój – naturalny wybór.* Wydawnictwo Uniwersytetu Łódzkiego.

Drabarczyk, K. (2017). Zrównoważony rozwój województw – analiza porównawcza. *Zeszyty Naukowe Politechniki Częstochowskiej. Zarządzanie*, *2*(25), 23–34. https://doi.org/10.17512/znpcz.2017.1.2.02.

Gaspars-Wieloch, H. (2012). Ograniczona skuteczność metod optymalizacyjnych w rozwiązywaniu ekonomicznych problemów decyzyjnych. *Ekonomista*, (3), 303–323. https://ekonomista.pte.pl/Ograniczona-skutecznosc-metod-optymalizacyjnych-w-rozwiazywaniu-ekonomicznych-problemow,155760,0,1.html.

Gupta, J., & Vegelin, C. (2016) Sustainable development goals and inclusive development. *International Environmental Agreements: Politics, Law and Economics*, *16*, 433–448. https://doi.org/10.1007/s10784-016-9323-z.

Ilić Krstić, I., Ilić, A., & Avramović, D. (2018). The three dimensions of sustainable development: Environment, economy and society. In *The 18th Conference of the series Man and Working Environment* (vol. 50; pp. 197–202).

Islam, H. (2025). Nexus of economic, social, and environmental factors on sustainable development goals: The moderating role of technological advancement and green innovation. *Innovation and Green Development*, *4*(1), 1–12. https://doi.org/10.1016/j.igd.2024.100183.

Kukuła, K., & Bogocz, D. (2014). Zero unitarization method and its application in ranking research in agriculture. *Economic and Regional Studies. Studia Ekonomiczne i Regionalne*, *7*(3), 5–13. https://www.ers.edu.pl/pdf-93141-27232?filename=ZERO%20UNITARIZATION%20METHOD.pdf.

Leń, P., Oleniacz, G., Skrzypczak, I., & Mika, M. (2016). The Hellwig's and zero unitarisation methods in creating a ranking of the urgency of land consolidation and land exchange work. In *16th International Multidisciplinary Scientific GeoConference. SGEM 2016, 30 June–6 July, 2016, Albena, Bulgaria: Conference Proceedings. Book 2 Geodesy and Mine Surveying, Photogrammetry and Remote Sensing: vol. 2 Geodesy and Mine Surveying* (pp. 617–624). International Multidisciplinary Scientific GeoConferences. https://doi.org/10.5593/SGEM2016/B22/S09.080.

Lindfors, A. (2021). Assessing sustainability with multi-criteria methods: A methodologically focused literature review. *Environmental and Sustainability Indicators*, *12*, 1–23. https://doi.org/10.1016/j.indic.2021.100149.

Łuczak, A., Cermakova, K., Kalinowski, S., Hromada, E., & Mec, M. (2025). Measurement of Sustainable Development and Standard of Living in Territorial Units: Methodological Concept and Application. *Sustainable Development*. Advance online publication. https://doi.org/10.1002/sd.3366.

Łuczak, A., & Just, M. (2020a). A Complex MCDM Procedure for the Assessment of Economic Development of Units at Different Government Levels. *Mathematics, 8*(7), 1–17. https://doi.org/10.3390/math8071067.

Łuczak, A., & Just, M. (2020b). The positional MEF-TOPSIS method for the assessment of complex economic phenomena in territorial units. *Statistics in Transition new series 21*(2), 157–172. https://doi.org/10.21307/stattrans-2020-018.

Łuczak, A., & Just, M. (2021). Sustainable development of territorial units: MCDM approach with optimal tail selection. *Ecological Modelling*, *457*, 1–21. https://doi.org/10.1016/j.ecolmodel.2021.109674.

Mensah, J. (2019). Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Social Sciences*, *5*(1). https://doi.org/10.1080/23311886.2019.1653531.

Poskrobko, B. (2009). Współczesne trendy cywilizacyjne a idea zrównoważonego rozwoju. *Przegląd Komunalny*, (6), 25–29.

Radzka, E., Rymuza, K., & Jankowska, J. (2015). The assessment of drinking water quality using zero unitarization method. *Archives of Environmental Protection*, *41*(4), 91–95. https://doi.org/10.1515/aep-2015-0043.

Roszkowska, E. (2011). Multi-criteria decision making models by applying the TOPSIS method to crisp and interval data. *Multiple Criteria Decision Making*, *6*, 200–230. https://mcdm.ue.katowice.pl/files/papers/mcdm11(6)_11.pdf.

Roszkowska, E. (2024). Modifying Hellwig's Method for Multi-Criteria Decision-Making with Mahalanobis Distance for Addressing Asymmetrical Relationships. *Symmetry*, *16*(1), 1–18. https://doi.org/10.3390/sym16010077.

Roszkowska, E., & Filipowicz-Chomko, M. (2021). Measuring Sustainable Development Using an Extended Hellwig Method: A Case Study of Education. *Social Indicators Research*, *153*(1), 299–322. https://doi.org/10.1007/s11205-020-02491-9.

Roszkowska, E., Filipowicz-Chomko, M., Łyczkowska-Hanćkowiak, A., & Majewska, E. (2024). Extended Hellwig's Method Utilizing Entropy-Based Weights and Mahalanobis Distance: Applications in Evaluating Sustainable Development in the Education Area. *Entropy*, *26*(3), 1–20. https://doi.org/10.3390/e26030197.

Stec, M., Grzebyk, M., Caputa, W., & Krawczyk-Sokołowska, I. (2024). A comparative analysis of the level of sustainable development in Polish voivodeships in 2012 and 2021. *Economics and Environment*, *89*(2), 1–15. https://doi.org/10.34659/eis.2024.89.2.766.

Sztumski, W. (2006). Idea zrównoważonego rozwoju a możliwość jej urzeczywistnienia. *Problemy Ekorozwoju, 1*(2), 73–76.

Trzepacz, P. (Ed.). (2012). *Zrównoważony rozwój – wyzwania globalne. Podręcznik dla uczestników studiów doktoranckich*. Instytut Geografii i Gospodarki Przestrzennej Uniwersytetu Jagiellońskiego. https://ruj.uj.edu.pl/server/api/core/bitstreams/30aa2a6f-b7fc-4c44-abf9-be00810af78d/content.

Ulmann, K. (2020). Ocena rozwoju społeczno-gospodarczego państw przyjętych w 2004 roku do Unii Europejskiej za pomocą wielowymiarowej analizy porównawczej. *Zeszyty Studenckie Wydziału Ekonomicznego Uniwersytetu Gdańskiego*, *10*, 156–168. https://czasopisma.bg.ug.edu.pl/index.php/naszestudia/article/view/4572/3981.

United Nations Secretary-General. World Commission on Environment and Development. (1987). *Report of the World Commission on Environment and Development: Our Common Future*. https://digitallibrary.un.org/record/139811?v=pdf.

Urząd Statystyczny w Katowicach. (2015). *Wskaźniki zrównoważonego rozwoju Polski.* https://katowice.stat.gov.pl/files/gfx/katowice/pl/defaultaktualnosci/760/11/2/1/wskazniki_zrownowazonego_rozwoju_2015.pdf/.

Vafaei, N., Ribeiro, R. A., & Camarinha-Matos, M. (2018). Data normalisation techniques in decision making: case study with TOPSIS method. *International Journal of Information and Decision Sciences*, *10*(1), 19–38. https://doi.org/10.1504/IJIDS.2018.090667.