What is the level of spatial autocorrelation of the green economy? The case study of voivodships in Poland

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Abstract: *In an era of resource scarcity, climate change, and environmental degradation, the growth of a green economy necessitates a new course for socio-economic development that successfully pursues sustainable development objectives. Among other things, variables related to demographics, the environment, technology, the economy, and society all contribute to its polarisation. The aim of the study is to understand what factors influence the development of the green economy in the various provinces of Poland, and how these factors may be related to each other in a spatial context. The selection of factors from 2010 to 2020 was the availability of Statistics Poland records. The study offers a spatial analysis of Poland's green economy in its provinces in 2010, 2019, and 2020. Spatial autocorrelation was found using spatial statistical methods, and the geographical pattern of the green economy's formation was shown. These analyses used measures of spatial autocorrelation, which allowed for the identification of spatial relationships of a particular characteristic throughout the whole research region and the connection between a particular place and nearby locations. Due to a combination of natural and geographic features, as well as the impact of socio-economic factors, each province in the nation has a unique economic climate, which determines its level of development and standard of life.*

Keywords: *Green economy, spatial differentiation, province, spatial autocorrelation measure, local Moran's coefficient, global Moran's coefficient, synthetic measure.*

JEL Classification: *C21, R12.*

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Introduction

The term "green economy" (GE) is a multifaceted idea encompassing financial, social, and infrastructure components. A significant challenge that will undoubtedly impact practically every economic sector is the shift from a traditional to a green economy (industry, trade, agriculture, tourism). A green economy (GE) prioritizes environmental health and quality of life over financial development and economic growth. In fact, it may even be said that these factors are marginally more essential. The shift from the conventional brown economy to the green economy will be a gradual, intricate, and transformative procedure (Kasztelan, 2017; Naik, 2021). The region has a number of difficulties, including enhancing resource efficiency, advancing low-carbon technology, cutting gas emissions, raising investment in the preservation of natural capital, and lowering economic inequality (Halle, 2011). The environmental, economic, and social justifications for the shift to an eco-friendly economy are well established. Environmental harm, declining air quality, rising greenhouse gas emissions, and declining water quality are all consequences of rapid economic expansion. Sustainable development is hampered by these environmental issues (Yi & Liu, 2015).

The transition from a linear to a closed-loop economy is being driven by the depletion of primary resources and the implications this has for the environment. Since closed-loop systems are thought to offer significant potential to save primary resources, safeguard biodiversity, and slow down global warming, CE is viewed as a sustainable development concept (Luthin et al., 2023). Sustainable development faces significant obstacles from the efficient use of mineral resources, their depletion, and the escalating effects of climate change. As mentioned by Hu and Gu (2024), simultaneously, the increasing impacts of climate change, exhibited by extreme weather events and ecological disruption, highlight the pressing necessity of a significant transition towards a sustainable economy, also known as the green economy.

The green economy lowers environmental dangers, promotes social justice, and increases prosperity. It incorporates goals that can be pursued by both local and national governments, including social, economic, and environmental ones. An economy that relies on fossil fuels for transportation, energy production, and production is known as a “brown economy.” Natural resources give regions the raw materials they require for industry and energy generation, the cornerstone of economic progress. There are detrimental environmental effects from their extraction, processing, and use, such as greenhouse gas emissions, forest loss, and water contamination (Akalibey et al., 2023).

The polarisation of green circular economy (CE) development across regions can be attributed to geographical location, level of economic development, and resource distribution. Geographical factors significantly shape the industrial structures of regions (Di et al., 2023). A region with few natural resources is more likely to form CE due to minimised consumption of natural resources (Robaina et al., 2020). As a consequence of economic activity, economic growth erodes natural capital. Green growth is important for both economic development and environmental improvement (Xu et al., 2022). Churski et al. (2021) highlight the importance of reconsidering the definition and use of regional development determinants in connection to socio-economic development processes, particularly those involving the growth of the green economy.

Local actors implement GE policy. Most research on GE focuses on the industry level or national scale. Regional aspects of GE are still under-researched. The article’s significance derives from its research findings on GE at the provincial level in Poland, covering the period from 2010 to 2020. The aim of the study is to understand what factors influence the development of the green economy in the different provinces of Poland, and how these factors may be related to each other in a spatial context. Analyzing the context of spatial autocorrelation allows us to better understand the degree of polarization among provinces and how differences among regions in the adoption of green economy principles may be related to their geographic proximity and specific local characteristics. The study used a variety of analysis methods, including a literature review, descriptive statistics and a synthetic measure to assess the overall degree of green economy adoption in each province. In addition, a measure of spatial autocorrelation was used, which made it possible to assess whether the development of the green economy in one region is related to development in neighboring areas. The authors proposed the following research questions to clarify regional differences in the green economy (GE) and better understand its regional aspects: What elements influence the development of the green economy? Which are the main and most important determinants of GE? What is the link between GE environment, health care and waste management spending, energy consumption and production, natural resource management and waste management and its level? What impact will the growth of the green economy have on the local economy?

In this study, Poland is chosen as a case due to its unique combination of rapid economic growth, reliance on coal, and significant regional disparities, all of which present distinctive challenges and opportunities in the shift toward a green economy. Unlike many other EU member states, Poland’s energy mix remains heavily dependent on coal, making the green economy transition more complex but highly relevant in the context of EU climate targets. Additionally, Poland's regional diversity (spanning from highly industrialized areas to predominantly rural regions) provides a rich landscape for examining spatial variations in green economy initiatives. The availability of detailed regional data from 2010 to 2020 further allows for a robust analysis, contributing to the broader understanding of how EU environmental strategies can be effectively tailored to member states with unique economic and energy profiles.

The originality of the article lies in its interdisciplinary approach, combining environmental, social, and economic variables, and the use of analytical methods in the analysis of the development of the green economy (synthetic measure, TOPSIS, and spatial autocorrelation). In addition, the originality lies in the study of specific regions (peripheral areas of the EU, voivodeships in Poland), which allows new conclusions to be drawn about local green economy initiatives. All these elements make the article contribute important conclusions to the scientific discourse, especially in the context of contemporary challenges related to the green economy and the assessment of progress in the green transition, by creating a synthetic indicator and identifying regions that need more support in the transition to the green economy, taking into account regional spatial dependencies.

1 Theoretical background

The transformation of the economy to a green growth path requires changes in the areas of competence, development, innovation, social awareness, and the natural environment. In fact, environmental protection has the potential to improve the process of sustainable development as well as the modernisation of a region, amongst other things. Society, the environment and the economy form a network of interconnectedness (Zaucha, 2012). The region-specific dimension of GE processes is based on spheres that are endowed with individual development dynamics and manifest their multidimensionality in the economic, cultural, social and environmental spheres, among others.

According to studies conducted by Myrdal (1957) and Perroux (1955), the degree of development in each region affects how desirable it is to the other. Von Stackelberg and Hahne (1998) indicate that economic growth occurs unevenly and is centered in areas referred to as geographical growth centers. The concentration of population, production, and service potential is correlated with the degree of polarization in a given location. Furthermore, as Gawlikowska-Hueckel (2005) notes, the degree of urbanization and the composition of the economic system also influence the absorption of polarization impulses.

The political backing, resource distribution, economic development level, and geographic location all contribute to significant spatial differences in GE development between geographical locations. Geographical variables play a major role in shaping the industrial structures of different regions, which leads to discernible variations in carbon emissions across them. Di et al. (2023) findings state that circular economy encourages material recycling and resource efficiency as a sustainable means of managing resources, reducing waste production, and bolstering renewable energy sources.

According to Akalibey et al. (2023), one crucial instrument for attaining sustainable development is the shift of economies from a brown to a green economy. The green economy lowers environmental hazards, promotes social justice, and enhances well-being. It combines goals that can be pursued by the business sector, local, regional, or federal governments, and the social and environmental domains. As stated by Murray (2017), building a green economy entails addressing environmental issues in addition to guaranteeing social stability, economic security, and the creation of new opportunities for sustainable growth. GE's basic tenet is that resources are obtained by other organizations through the recycling process of wasted materials. Reducing, reusing, recycling, and recovering are the "4Rs" that are associated with the green economy. These speak of lowering resource usage, protecting natural capital, and recovering resources. In line with Elimam's (2017) research, this enhances the quality of life for locals and boosts the region's economy by offering more efficient methods to use resources, reducing environmental pollution, and encouraging green growth. It appears to point to a sharing economy as well. The comprehensive use of resources and sustainable management are the main goals of waste management.

Ralph (2021) points out that the linear economic model has resulted in pollution and the wasteful exploitation of natural resources. Utilizing recyclable materials again is a component of the circular economy (CE). Moreover, as Kirchherr et al. (2017) point out, CE has emerged as a primary tactic for resolving environmental issues. While CE's consequences on the environment have received a lot of attention, its effects on the economy and society have received less attention. Decision-makers at the national, regional, and municipal levels are increasingly focusing on CE as a key component of a sustainable economy (OECD, 2020). Mhatre et al. (2021) state that the goals of CE are to reduce resource consumption and the resulting environmental impact, as well as to maximize material efficiency.

According to the research study by Prieto-Sandoval et al. (2018), the term circular economy represents a sustainable development paradigm. It encourages waste reduction, closed-loop systems, and resource efficiency to reduce environmental effects while advancing the development process.

Promoting economic growth and development, as indicated by Fan and Wang (2024), while preserving the ecosystems and resources necessary for humanity's survival is known as green growth. Reducing the amount of material extracted from the environment is necessary to preserve the environment while reaping its benefits. To achieve this, we must change the way we consume and produce goods and services. Our economy must be greened. A green economy is one that cares about the environment and the welfare of society when choosing goods and services (Fan & Wang, 2024). According to Stoian et al. (2023), sustainability objectives, like those of a green economy, must take into account the opportunity costs of decisions, as well as the short- and long-term positive externalities. The intricate interplay among the environment, society, and economics gives rise to all of these factors.

Given the environmental, social, and economic aspects of green infrastructure, the green economy is a sustainable economy. Declining air quality, depopulation (suburbanization process, aging population), poverty, and unemployment, poorer growth in entrepreneurship, substantial spatial (intra-regional) divergence of regions, strong growth in trash, and capital leaching are its key issues for regions. These processes have the potential to drastically deteriorate the environment, alter the demographic makeup, and make certain areas less desirable. It is a route for economic growth that will be feasible in a sustainable manner while keeping environmental requirements and limitations in mind. Sustainable development can be accomplished with its help (Khoshnava et al., 2019).

The Green New Deal and the green economy are related. Its concept entails incorporating environmental considerations into strategies for social and economic rehabilitation following the financial crisis. Integrating social and economic inequality with climate change into national, regional, and local public policy was the goal of the Green Deal's policies and policy instruments. The European Green Deal intends to make the EU a modern, resource-efficient, and competitive economy while addressing the problems caused by climate change and environmental deterioration (Rivas et al., 2021).

Natural capital, entrepreneurship, and environmental quality of life should all be areas that are regularly evaluated under GE (OECD, 2014). It is important to track social aspects of the environment or economy in terms of GE, as well as the interaction between the two (OECD, 2011). None of the indicators provided by UNEP (United Nations Environment Programme) are chosen at random. It suggests an approach for developing systems of these indicators, presuming that nations (or regions) ought to develop a set of assessment indicators in accordance with their unique circumstances (environmental, social, and economic) (UNEP, 2012).

A set of metrics was put up by Broniewicz et al. (2022) to evaluate legislation in terms of the needs for climate change adaptation (and consequently, adjustments in the shift to a green economy). A set of metrics focused on natural capital, governmental policies promoting the green economy, and socio-economic challenges were identified by Ryszawska (2013). Forest area, protected areas, energy productivity, energy consumption, the production of non-renewable energy, trash recycling, spending on environmental development and broadcasting, environmental innovation, employment, and policy instruments are a few examples of indicators.

The shift to a green economy is an unavoidable path for development, necessitating greater efforts to advance the growth of the green economies at the local, regional, and national levels. Individual economies' capacities and national interests must be considered. In terms of geography it refers to the efforts made to improve living circumstances, lessen the environmental impact on local and regional systems, and increase competitiveness on both fronts (Hahnel, 2010). As indicated by Herodowicz (2018), the green economy influences economic growth and helps the area meet environmental and climate goals. As noted by Lorek and Spangenberg (2014), this notion is incompatible with the requirements of a regionally balanced development.

Although several studies have analyzed the green economy at national scales in Western Europe (e.g., Germany, Italy), few have addressed the spatial differentiation of green economy measures in post-communist, coal-reliant countries like Poland. This research fills that gap by offering a detailed analysis of regional disparities, applying spatial autocorrelation to explore the unique challenges Poland faces in transitioning toward a sustainable economy. Atalay and Akand (2023) performed spatial analysis using LISA (Local Indicators of Spatial Association) and examined green economy indicators across OECD countries. The research highlighted the spatial relationships between economic growth and environmental pollution, providing a useful comparative framework for analyzing similar patterns in Poland. Including this research could demonstrate how our study adds unique insights into green economy transitions in a post-communist country like Poland, which is heavily reliant on coal compared to other OECD nations. Qin et al. (2024) analyzed the interactive response between green finance and productivity using spatial autocorrelation, providing a foundation to compare how financial mechanisms influence green economy transitions across different regions. This would be relevant for demonstrating how your study focuses more on spatial disparities within a coal-reliant economy, which differs from the financial and industrial context of China. This study explores the spatial interaction between green finance and productivity across Chinese provinces using spatial econometric techniques. It highlights regional differences and provides insights on how local economic policies can influence green productivity. The study identifies gaps in understanding how green finance impacts different regional economies, offering a valuable comparison with your research on Poland's green economy. Zhou et al. (2023) explore the relationship between renewable energy deployment and green economic growth, utilizing spatial regression techniques to assess regional spillover effects. They highlight gaps in renewable energy policies' effects on green growth across different regions, which could be relevant to our analysis of spatial patterns in Poland's energy-dependent regions.

The concept of a green economy encompasses a multitude of dimensions pertaining to sustainable development. It is this very multidimensionality that is pivotal to the realisation of sustainable, long-term socio-economic development. Poland, with its diverse economic, ecological and social structure, offers a wide range of conditions that can affect the effectiveness of green economy implementation in different regions. The selection of provinces allows for the examination of these differences and a more nuanced understanding of the regional specifics that determine the effectiveness of green activities. These variations encompass a range of factors, including the diverse natural resources that inform environmental policy, as well as local challenges related to industry, agriculture, or water management. Poland is distinguished by significant disparities in economic, social, and environmental development across its provinces. Different regions exhibit varying degrees of natural resource endowment, infrastructure, environmental policy, and industrial development. The analysis of the voivodeships enables the identification of these differences and an understanding of their impact on the implementation of green economy principles. By undertaking an analysis of individual provinces, it is possible to make the necessary adjustments to green activities in order to meet the specific needs of the region. The natural resources available in each of Poland's provinces exert a significant influence on the development of the country's green economy. For instance, provinces with a high proportion of forest cover (such as the Podlaskie and Lubuskie voivodeships) may prioritise the protection of biodiversity, whereas agricultural regions (such as the Wielkopolskie and Mazowieckie voivodeships) may focus on the development of sustainable agricultural practices. The selection of provinces permits a comprehensive examination of the utilisation

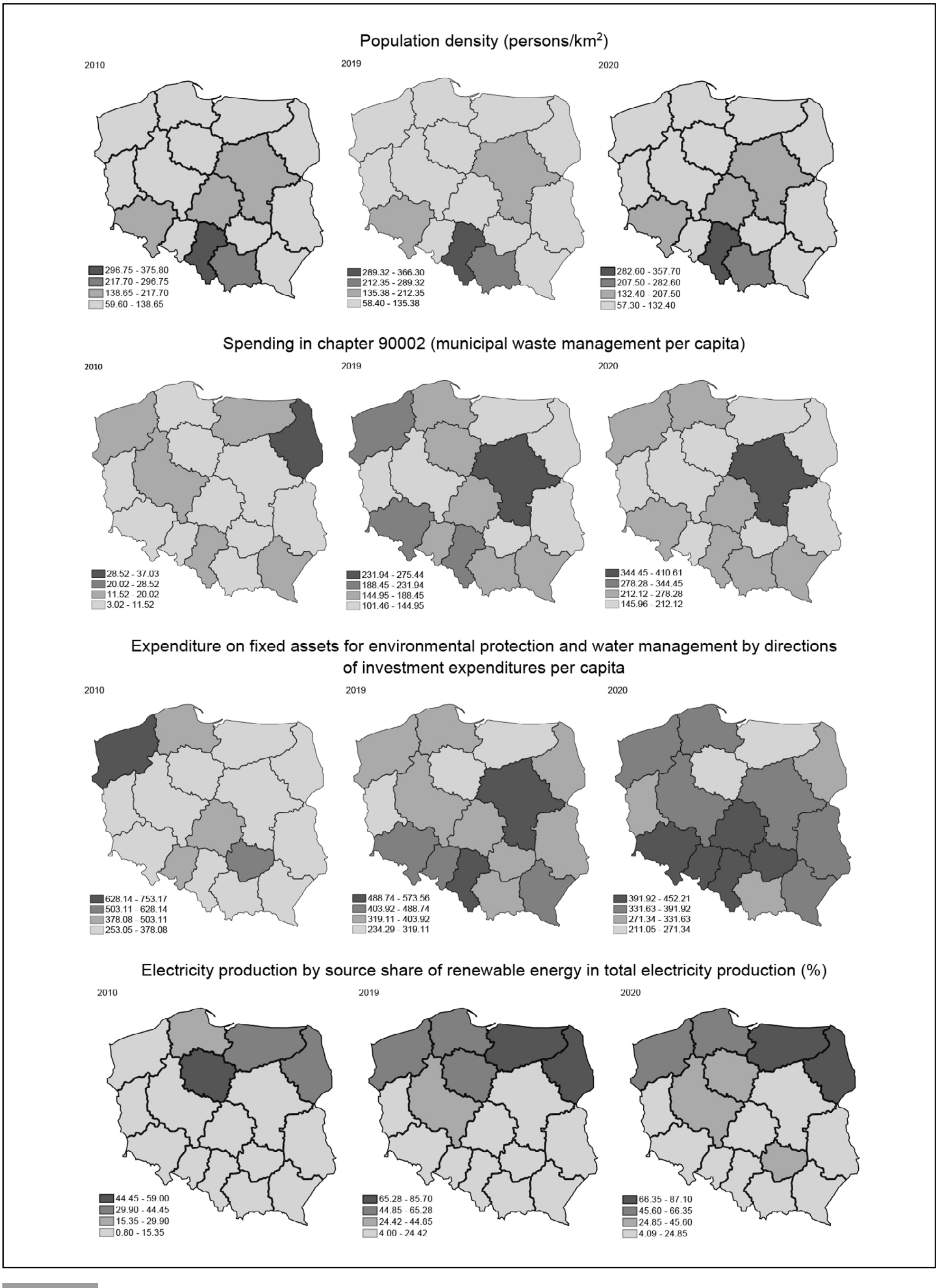

Fig. 1: The specifics of Poland's voivodeships selected variables – Part 1

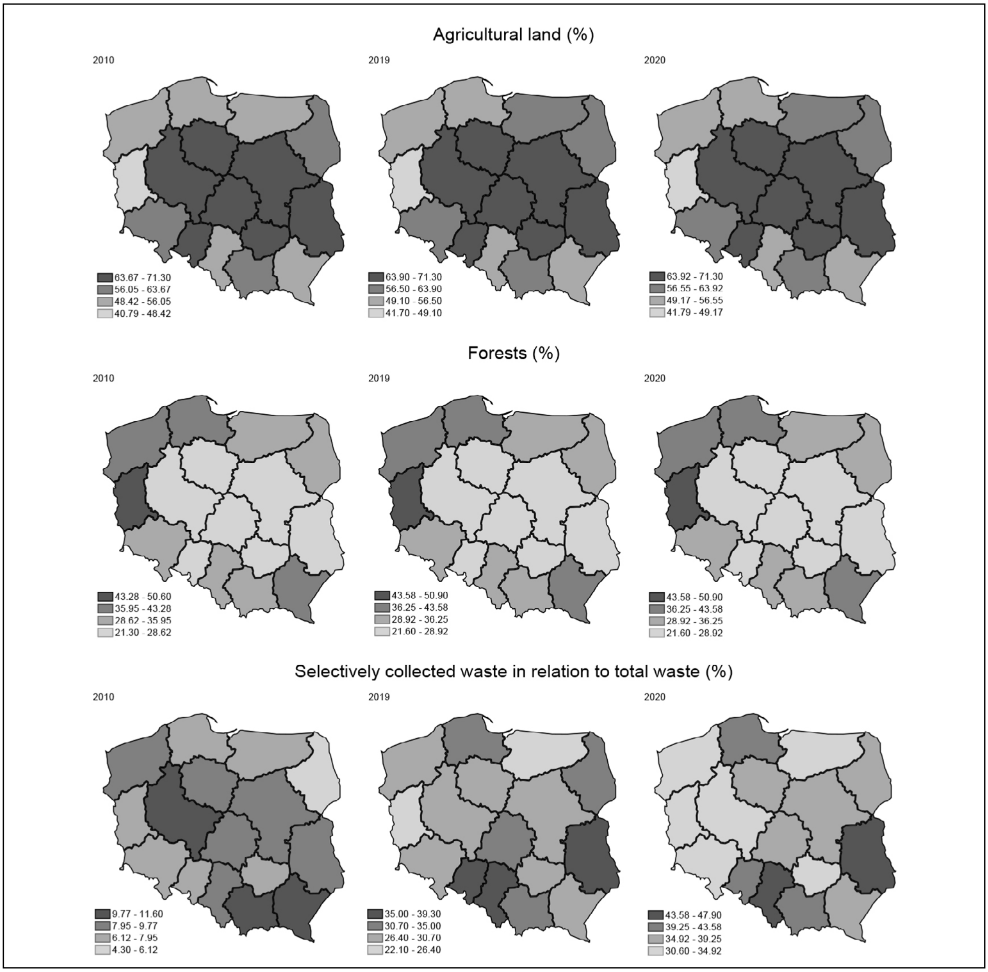

Fig. 1: The specifics of Poland's voivodeships selected variables – Part 2

Source: own (based on data from Statistics Poland)

of these resources in the context of the green economy (Fig. 1). This approach also facilitates a more nuanced comprehension of the interrelationships between regional ecological and economic processes, which can inform the development of efficacious green growth policies in the future.

The population density of Poland between 2010 and 2020 was characterised by a general trend of decline, with the exception of a few provinces (e.g., Małopolskie and Mazowieckie), where an increase was observed. These trends can be attributed to a combination of migration processes and demographic changes. The Polish population is characterised by an ageing demographic and a low birth rate, which has an adverse effect on population stability. An analysis of municipal waste management expenditures (in PLN per capita) in Poland from 2010 to 2020 reveals a trend of increasing waste management expenditures. This may be attributed to a growing population and rising costs associated with waste segregation, processing and landfilling. There is evidence of an increase in investment in environmental protection between the years 2010 and 2020. However, a slight decrease is observed in 2020 in comparison to 2019. Regional disparities indicate elevated expenditure in more developed provinces, including Silesia, Mazovia and Lower Silesia, as well as in provinces that have historically allocated significant resources to infrastructure development, such as West Pomerania. In provinces with lower outlays, such as Warmian-Masurian and Kuyavian-Pomeranian, the decline in investment may be indicative of a reduction in environmental priorities. The majority of provinces demonstrated an increase in the proportion of renewable energy sources (RES) utilized in electricity generation between 2010 and 2020. The proportion of forest cover in Poland is gradually increasing as a consequence of sustainable development, afforestation and environmental protection initiatives. The provinces of Lubuskie, Podkarpackie and Pomorskie are characterised by a high proportion of forest cover, whereas other forms of land use, including agriculture, are more prevalent in Łódź and Kujawsko-Pomorskie. An analysis of data on the selective collection of waste in relation to the total volume of waste generated in Poland between 2010 and 2020 reveals a notable increase in the efficiency of selective waste collection. This suggests that Poland's waste management systems have undergone a positive transformation, reflecting a growing environmental awareness among the general public. In conclusion, the upward trajectory of selective waste collection in Poland is a favourable development and represents a significant stride towards sustainable resource management (Fig. 1).

In Poland, as in other countries within the European Union, there is an emerging trend towards the implementation of measures designed to advance environmental protection, sustainable development and the efficient management of resources. Consequently, the examination of the extent to which a green economy is being pursued at the provincial level represents a valuable instrument for the identification of regions that have attained a superior level of sustainable development and those that necessitate further assistance in this regard. In this context, an investigation into the spatial autocorrelation of the green economy in Poland's provinces will facilitate the formulation of conclusions regarding the spatial mechanisms influencing sustainable development and the identification of factors that can be employed to enhance regional policies.

The authors set forth the following hypotheses:

H1: There is positive spatial autocorrelation of green economy indicators across regions in Poland, indicating that regions with high green economy performance group together.

H2: Provinces with historically high dependence on coal show lower green economy growth rates compared to others.

H3: Health care spending and waste management spending have a positive autocorrelation, indicating that these two areas have a reciprocal effect on green economy growth.

2 Research methodology

The process of creating the synthetic measure – the green economy, which uses as the foundation for evaluating, involves the following steps: choosing the diagnostic variables and the study area; normalizing the variables using a zero-based unitization method; creating the synthetic measure using the chosen aggregation formula (TOPSIS method); linearly ordering the objects; and extracting typological classes for the entire synthetic measure's variation area (by analyzing spatial autocorrelation, correlation coefficient, bag diagram, and maps of spatial differentiation).

The empirical data was gathered between 2010 and 2020, with a focus on Poland's 16 voivodeships, from a spatial perspective (as a periphery territory of the EU). A voivodeship is the highest level of the country's basic geographical division and is a unit of local government, i.e., a regional self-government community (all residents), established to carry out public administration functions.

The choice of 2010, 2019 and 2020 was dictated by several factors related to the availability of data within official statistics and evolving socio-economic conditions. The year 2010 was chosen as a baseline because it represents a period of economic stabilization following the global financial crisis, making it an appropriate starting point for the analysis of trends in the green economy. The year 2019 was chosen to represent the most recent period prior to the pandemic, thus capturing the state of the green economy prior to the significant disruption caused by COVID-19. The year 2020 was included to assess the direct impact of the pandemic on the transformation of the green economy, as it had a unique and profound impact on economic and environmental processes worldwide. Intermediate years were omitted mainly due to inconsistencies and gaps in data availability for some variables in official statistics. The years selected are intended to provide a clear and comparable picture of the main economic and environmental developments while recognizing the limitations of data comparability and changing legislation.

In analyzing the performance of the voivodeships, it is important to take into account the social, economic, and environmental determinants of endogenous potential. There is an interplay between the determinants of the green economy. The determinants are a group of interdependent phenomena occurring simultaneously within the same area. The selection of the twelve variables is based on previous research that demonstrates their relevance to sustainability and the green economy. Healthcare investments have been proven to cause environmental damage through emissions but also promote sustainability indirectly by improving public health (Berniak-Woźny & Rataj, 2023). Expenditures on waste management are essential in enabling waste reduction and recycling, which are essential elements for reducing the environmental footprint (Patwary et al., 2024). Fixed asset expenditure on environmental protection and water management plays a crucial role in controlling CO_2 emissions and water conservation, fostering green economic development (Rivas et al., 2021). Electricity consumption in rural areas, especially the reliance on non-renewable sources of energy, affects environmental performance, while clean energy adoption supports sustainability. Electricity generation and renewable energy generation constitute the essence of environmental sustainability, with the former reducing emissions and facilitating sustainable development (Robaina et al., 2020). The proportion of agricultural land to total area is important as sustainable agriculture has a positive impact on environmental and economic performance (Berniak-Woźny & Rataj, 2023). Proportion of forests in total area facilitates carbon sequestration and habitat for biodiversity, improving environmental performance (Rivas et al., 2021). Legally protected areas play an important role in biodiversity conservation and mitigate human influence. The ratio of ecological species enables long-term environmental health through biodiversity, whereas the lowering of the percentage of operating landfills mitigates emissions and pollution (Patwary et al., 2024). Lastly, selective waste collection

Tab. 1: A list of variables that characterize the green economy

Variable number	Variables	Unit
X_1	*Expenditure on healthcare*	PLN/pc
X_2	*Spending on waste management*	1,000 PLN/pc
X_3	*Expenditure on fixed assets for environmental protection and water management*	PLN/pc
X_4	*Electricity usage in rural areas*	kWh/pc
X_5	*Overall electricity generation*	GWh/pc
X_6	*Electricity production from renewable sources*	GWh/pc
X_7	*Proportion of agricultural land in total area*	%
X_8	*Proportion of forests in the total area*	%
X_9	*Proportion of legally protected areas in the total area*	%
X_{10}	*Proportion of ecological species in the total area*	%
X_{11}	*Proportion of active landfills in the total area*	%
X_{12}	*Proportion of selectively collected waste in total waste*	%

Source of data: own (based on the Statistics Poland (stat.gov.pl)) enhances recycling and restricts environmental effects, and it is linked directly to waste management performance (Stoian et al., 2023). These factors are backed by empirical studies and are central to the examination of the green economy and sustainability.

These factors constitute a complex web of interconnected variables that form a multidimensional space. In the investigation, the variables listed in Tab. 1 were differentiated. Additionally, Tab. 2 depicts the descriptive statistics of these variables. Each of the selected variables plays a pivotal role in evaluating the status and efficacy of the green economy, as it encompasses a tripartite approach encompassing environmental, social, and economic aspects. The selected variables encompass pivotal domains that, collectively, facilitate a comprehensive representation of the green economy at the provincial level. The analysis enables the identification of provinces that are effectively implementing the green economy and those that require improvement. This provides a basis for informed political and economic decisions to promote the green transition.

The features satisfying the inequality were removed from the set of variables, where V^* stands for the coefficient of variation's critical value. The critical value was determined to be $V^* = 0.10$ (Kukuła, 2000). It is considered that if the correlation coefficient between the examined features is found to be excessively high, a representative should be chosen, typically based on merits (the correlation coefficient's threshold level is typically $r^* = 0.75$) (Malina, 2004; Młodak, 2006). Using Statistica software, an exploratory factor analysis was performed, which strengthened the process of variable selection.

The definition of an observation matrix, including objects and features, was facilitated by the choice of straightforward variables and their content and statistical verification. It was written as X_{ij}:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (1)$$

where: X_{ij} denotes the values of the j^{th} variable ($j = 1, 2, ..., m$) for the i^{th} object ($i = 1, 2, ..., n$), matrix of objects.

Tab. 2: Descriptive statistics of variables that characterize the green economy

Variables	Average	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation
Expenditure on healthcare	41.673	8.160	131.280	496.723	21.322	52.373
Spending on waste management	0.021	0.000	0.100	0.000	0.016	71.280
Expenditure on fixed assets for environmental protection and water management	376.656	206.460	753.170	8,809.878	91.668	24.188
Electricity usage in rural areas	813.533	532.200	1,055.200	13,187.505	114.735	14.109
Overall electricity generation	0.004	0.000	0.014	0.000	0.004	87.651
Electricity production from renewable sources	0.001	0.000	0.003	0.000	0.001	81.912
Proportion of agricultural land in total area	58.675	20.100	71.300	104.248	10.010	17.126
Proportion of forests in the total area	30.800	21.300	50.900	55.126	7.425	24.107
Proportion of legally protected areas in the total area	33.490	18.170	65.000	170.264	13.049	38.963
Proportion of ecological species in the total area	0.001	0.000	0.003	0.000	0.001	73.207
Proportion of active landfills in the total area	0.000	0.000	0.000	0.000	0.000	45.408
Proportion of selectively collected waste in total waste	25.392	4.300	47.900	16.259	3.795	17.044

Source: own (based on the Statistics Poland (stat.gov.pl))

The direction of the variable preferences in respect to the general criterion under consideration was ascertained in the following study stage, where they were classified as stimulants and destimulants (Wysocki, 2010). According to the classification in the set of diagnostic variables selected for the construction of the synthetic measure of green economy of voivodships in Poland, the following were distinguished: S (stimulant) = $\{X_1, X_2, \ldots, X_m\} = \{X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{12}\}$ and D (destimulant) = $= \{X_1, X_2, \ldots, X_m\} = \{X_{11}\}$.

It is challenging to directly compare and add diagnostic factors since they typically have distinct titers and ranges of variation (Malina, 2004). The zeroed unitarization process was applied to the chosen variables using the following formula:

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

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

where: S – the stimulant; D – the destimulant; $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$; $\max x_{ij}$ – the maximum value of the j^{th} factor; $\min x_{ij}$ – the minimum value of the j^{th} factor; x_{ij} – the value of the j^{th} factor for this object (Kukuła, 2000).

Regarding their range of variability and placement inside the observation space, every variable is standardized. After unitarization, we are left with a matrix of feature values – Z_{ij} ($\in [0; 1]$):

$$Z_{ij} = \begin{bmatrix} z_{11} & z_{12} & \ldots & z_{1m} \\ z_{21} & z_{22} & \ldots & z_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ z_{n1} & z_{n2} & \ldots & z_{nm} \end{bmatrix} \quad (4)$$

The aggregation functions are used to estimate the values of the synthetic variable; these functions can take several analytical forms. Based on the following formula, the synthetic measure for each individual object was established:

$$q_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (5)$$

With the proviso that: q_i [0; 1] ($i = 1, 2, \ldots, n$) is the value of the synthetic measure; d_i^- represents the distance of the object from the anti-pattern (from 0), and d_i^+ represents the distance of the object from the pattern (from 1). A greater measure value denotes an improved individual's circumstances inside the examined region (Dziekański et al., 2022).

During the last phase of the study, the synthetic measure, the "green economy," was interpreted using a typological grouping. Bagged graphs were invited, the Spearman rank correlation coefficient was evaluated, and a spatial autocorrelation analysis was carried out. From the perspective of advantages of the approach, spatial autocorrelation reveals the extent to which the green economy metrics in one region are related to those in neighboring regions (to understand regional dependencies). This can help policymakers target regions with similar challenges and opportunities, enabling more region-specific interventions. By identifying areas with similar values, spatial autocorrelation helps in grouping regions with common characteristics, making it easier to tailor regional policies to specific needs. However, there are also some disadvantages, because the accuracy of spatial autocorrelation can be highly dependent on the granularity and quality of data (data limitation). In regions where data is sparse or outdated, spatial autocorrelation may not accurately reflect real patterns. The positive autocorrelation might indicate clusters of regions with both high and low green economy performance, which can complicate interpretations about which clusters should receive priority attention. Maps illustrating the spatial variation of the synthetic measure of the "green economy" were included in the outcome assessment.

Four classes were determined using the mean ($\bar{x}$) standard deviation (S_d). The first group has the most developed voivodeships, and the last group (because of the green economy measure) has the least developed voivodeships. The following formulas were used to group the data:

$$\begin{aligned} &\text{Group 1; } \bar{x} + S_d \le q_i \\ &\text{Group 2; } \bar{x} \le q_i < \bar{x} + S_d \\ &\text{Group 3; } \bar{x} - S_d \le q_i < \bar{x} \\ &\text{Group 4; } q_i < \bar{x} - S_d \end{aligned} \quad (6)$$

When spatial autocorrelation is present, objects that are geographically close to each other tend to exhibit greater similarity in the variable being studied and have a tendency to form clusters. As a result, these objects can combine to form spatial clusters. When we see a spatial accumulation of high or low values for the measured variables, we get positive spatial autocorrelation. A checkerboard pattern is the visual representation of negative autocorrelation, which is defined as adjacent high values with low values and low values with high values in the space (Suchecki, 2010). Finding groups of related objects can be accomplished by examining the autocorrelation result. It is easier to anticipate changes and to implement development policy when one is aware of and comprehends the structures of space (Sikora, 2009).

A technique that allowed for the determination of whether surrounding units form clusters with similar values of the synthetic measure is the Moran's I global statistic. The following formula (Anselin, 1995; Cliff & Ord, 1973; Longley et al., 2006; Upton & Fingleton, 1985) was used to determine it:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,(x_i-\bar{x})(x_j-\bar{x})}{S_0\,\sigma^2} \quad (7)$$

When an area is surrounded by regions that have significantly differing values for the variable under study, the local Moran's I statistic goes negative (and vice versa). As a result, clusters with either low or high values of the variable under investigation (Global Moran's statistics) can be identified. The most widely used analysis is the local variant of Moran's I statistics, or LISA (Local Indicators of Spatial Association) (Moran, 1950; Ullah & Giles, 1998). The following formula determines the local version of the Moran's I coefficient:

$$I_i = \frac{(x_i-\bar{x})\sum_{j=1}^{n} w_{ij}\,(x_j-\bar{x})}{\sigma^2} \quad (8)$$

where: n – total count of spatial objects (number of points or polygons); x_i, x_j – the values of the factors for the compared objects; $\bar{x}$ – mean value of the factors for all objects; w_{ij} – elements of the spatial weight matrix (row-standardized weight matrix);

$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}$; $\sigma^2 = \frac{\sum_{j=1}^{n}(x_i-\bar{x})^2}{n}$

– the square of the dispersion (Cliff & Ord, 1973; Longley et al., 2006).

A value from the interval (−1, 1) is used for Moran's I statistics, which show statistically significant clusters of similar values in nearby places. A value of "0" indicates no spatial autocorrelation (Janc, 2006).

Using the Queen matrix standardized by rows to one, Moran's I statistics were computed to show the regional dependency of the green economy in Poland's voivodships. The PQStat application was used to perform the computations.

3 Results and discussion

3.1 Results

The polarization in the green economy is a defining feature of Poland. Historical and ecological factors have contributed to this divergence. Larger and medium-sized cities also have an impact on it, and there is evidence of social and economic connection. It may prove challenging for voivodships (e.g., Śląskie, Dolnośląskie) where industry plays a pivotal role in their economies to transition to more environmentally sustainable economic models. Furthermore, ecological factors, such as disparities in the accessibility of natural resources, including agricultural land, forests, and protected areas, influence the implementation of environmentally friendly measures. In 2010 and 2020, the synthetic green economy measure ranged from 0.31 to 0.42 and 0.40 to 0.53, respectively. The synthetic measure's mean, minimum, and maximum are all rising. A greater polarity of the gap is indicated by an increase in its magnitude. A decrease in polarization was shown by the synthetic measure's coefficient of variation, which had a value between 0.08 and 0.07. The reduction in the coefficient of variation may also indicate stabilisation processes in which the differences between the provinces, although they still exist, are not growing as fast as before.

The split of Poland's voivodships based on the value of the synthetic green economy metric is depicted in Fig. 2. Units with a lower measure value are shown by lighter colors, and a set of voivodeships with a larger measure value are indicated by black colors.

Tab. 3 displays a modest negative autocorrelation for the green economy measure throughout the examined time, using the calculated global values of Moran's I. A decreasing spatial reliance is indicated by the studied statistics' declining value. This implies that

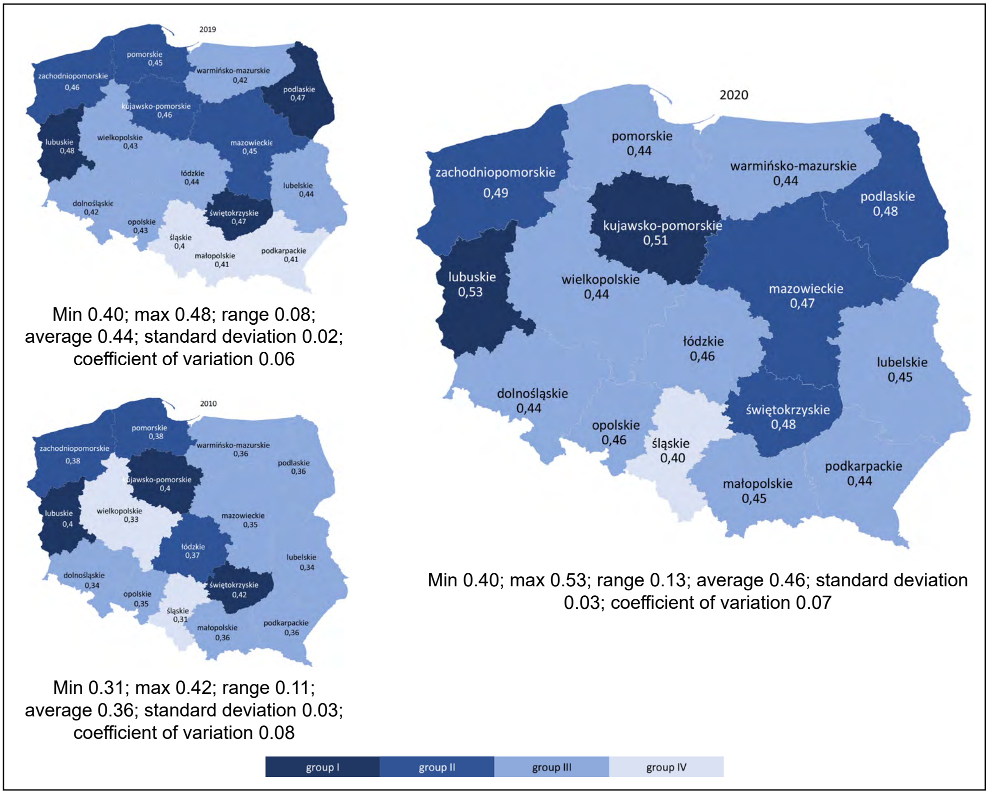

Fig. 2: **Synthetic measure of green economy in voivodships in Poland (2010, 2019, 2020)**

Source: own (based on the Statistic Poland data)

Tab. 3: **Synthetic green economy measure in Poland's voivodships by Moran's I (2010, 2019, 2020)**

	2010	2019	2020
Moran's I	−0.195	−0.026	−0.130
Expected I	−0.067	−0.067	−0.067
Assuming normality			
Variance I	0.022	0.022	0.022
Statistics *Z*	−0.864	0.276	−0.427
Value *p*	0.388	0.783	0.670
Assuming randomness			
Variance I	0.022	0.024	0.021
Statistics *Z*	−0.866	0.267	−0.436
Value *p*	0.386	0.789	0.663

Source: own (based on Statistics Poland data) every level of the green economy that has been observed has an equal chance of occurring somewhere. In terms of voivodships, it may be said that the green economy does not exhibit spatial autocorrelation. This indicates a propensity to concentrate comparable values, or high and low values, on the researched variable's area inside a certain location.

In the subsequent analytical stage, local Moran's I statistics were calculated for each voivodeship (with their spatial differentiation illustrated in Fig. 3). The following voivodeships exhibited significant and positive values of the local Moran's I statistics: Opolskie (0.422), Zachodniopomorskie (0.146), Pomorskie (0.093), Dolnośląskie (0.091), Podlaskie (0.052) in 2010 (Zachodniopomorskie 0.252, Małopolskie 0.239, Mazowieckie 0.077, Oposkie 0.033, Podkarpackie 0.027; in 2020), which suggests the presence of local clusters with similar levels of green economy. This implies that these provinces were more consistent in terms of green policies, with a tendency to spatially concentrate similar results. The negative was obtained for the following voivodeships: Lubelskie (−0.272), Wielkopolskie (−0.464), Lubuskie (−0.608), Śląskie (−0.792), Świętokrzyskie (−1.057) in 2010

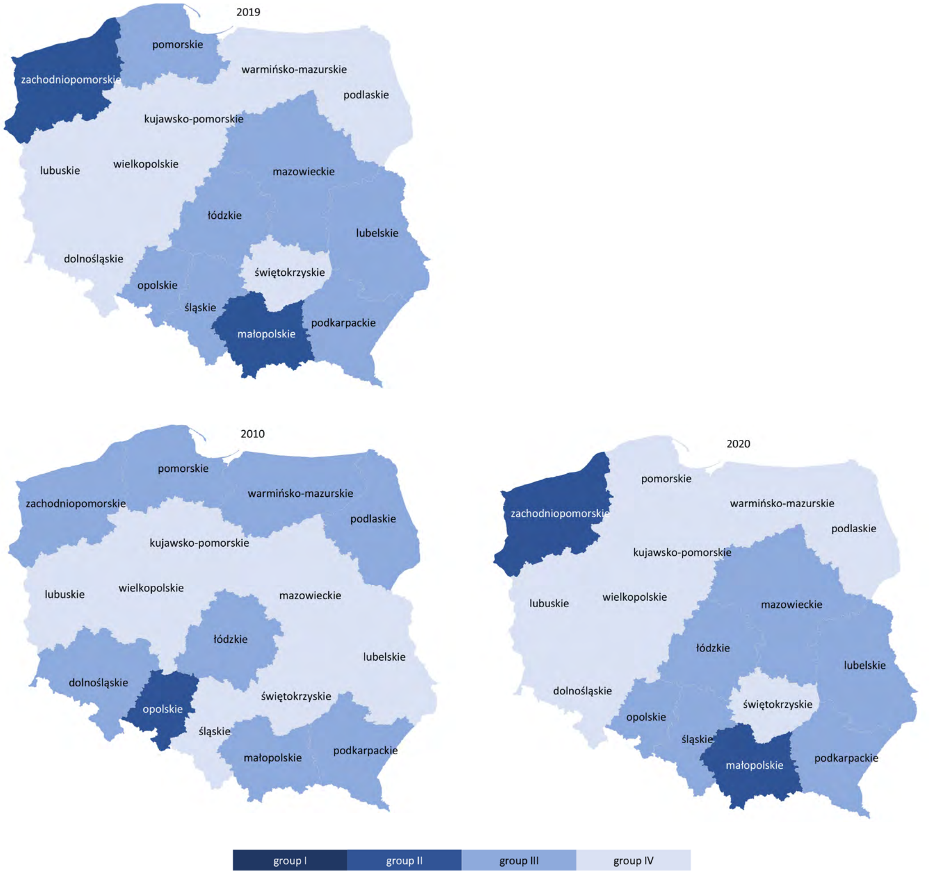

Fig. 3: Synthetic green economy measure in Poland's voivodships by local Moran's I (2010, 2019, 2020)

Source: own (based on Statistic Poland data)

(Świętokrzyskie −0.305, Wielkopolskie −0.308, Lubuskie −0.316, Dolnośląskie −0.328, Kujawskopomorskie −0.549; in 2020), indicating a spatial split and lack of strong links between high and low green economy regions. This situation may suggest that there is a divergence in the implementation of environmental policies in these provinces or other factors that prevent their effective implementation across the region. This phenomenon may be due to various conditions, such as the structure of the economy, the availability of financial resources for environmental investment, or the diversity of green infrastructure.

The western, eastern, and central provinces of Poland (Zachodniopomorskie, Małopolskie and Mazowieckie) exhibited elevated values for the Moran statistic, which may suggest an enhancement in the consistency with which green economy measures are implemented. This may indicate an improvement in the effectiveness of green policies and their more effective implementation, which has resulted in a greater concentration of results in these provinces. It may be posited that these changes are the consequence of an increased focus on green transformation within national and regional development strategies, coupled with a rise in environmental awareness and the mobilisation of resources to achieve sustainable development goals. Conversely, voivodeships such as Świętokrzyskie, Wielkopolskie, Lubuskie and Kujawsko-Pomorskie exhibited negative values, indicating that these regions remain less integrated with regard to green policies and green development. This may indicate that there is still a divergence of green economy measures within them, and that there is a significant spatial variation in the level of implementation of these measures. This points to the possibility of difficulties in implementing unified green policies in these provinces, which may be due to a variety of local challenges, such as lower levels of investment in green infrastructure, greater reliance on traditional industries or difficulties in integrating actions at the local level.

Fig. 4 shows the relationships between variables in pairs and pinpoints data clusters. Groups of statistically comparable voivodeships, including outliers, are shown in the bag chart. The visual shape of these groups in succeeding years may suggest their distinction. The changes in the shape of the groups indicate the dynamics processes involved in the implementation of the green economy, as well as differences in the development of the provinces. Pearson correlation coefficient between *q* quality of life and *q* green economy and the value of the synthetic green economy measure: −0.1424, −0.2324, and −0.1654 (2010, 2019, and 2020) and with *q* financial situation: −0.2639, −0.1703, and 0.1680. This suggests that the spatial differentiation within the study area was relatively unstable (this is also indicated by the shape of the bags in the Fig. 4). In 2020, the outliers in our relations were two voivodeships: Silesian, Masovian, Lubusz, and Lublin Voivodship (Śląskie, Mazowieckie, Lubuskie, Lubelskie). These values suggest that improvements in the quality of life do not always go hand in hand with the development of green activities, and that external factors such as the financial situation or the level of infrastructure development may have a greater influence on these variables. The results of the analysis indicate that the spatial differentiation of the green economy in Poland is unstable and variable, suggesting that changes in this area do not occur uniformly. This variation may be the result of both local socio-economic conditions and specific regional policies, which have different impacts on the implementation of green activities. Variations in the correlations between variables also indicate the difficulty of achieving consistent, positive effects of the green economy across the country.

The relative change 2020/2019 and the measure's level in 2020 had a Pearson correlation value of 0.5795. This means that over this period, there has been a significant increase in the relationship between the level of the green economy and the changing dynamics of its development in different provinces. This is where the change 2020/2010 had a coefficient of 0.1953. Such a result suggests that, despite some progress in the development of the green economy, changes in the green economy were less dynamic and the relationship between 2010 and 2020 was less clear. The scatterplot displays a change in spatial polarization. In the two relationships under investigation, the top regions were: Pomorskie, Kujawsko-Pomorskie, Śląskie, Lubuskie (Fig. 5). This may indicate the effectiveness of the environmental policies implemented in these provinces, as well as their greater willingness to invest in sectors related to environmental protection and sustainable development.

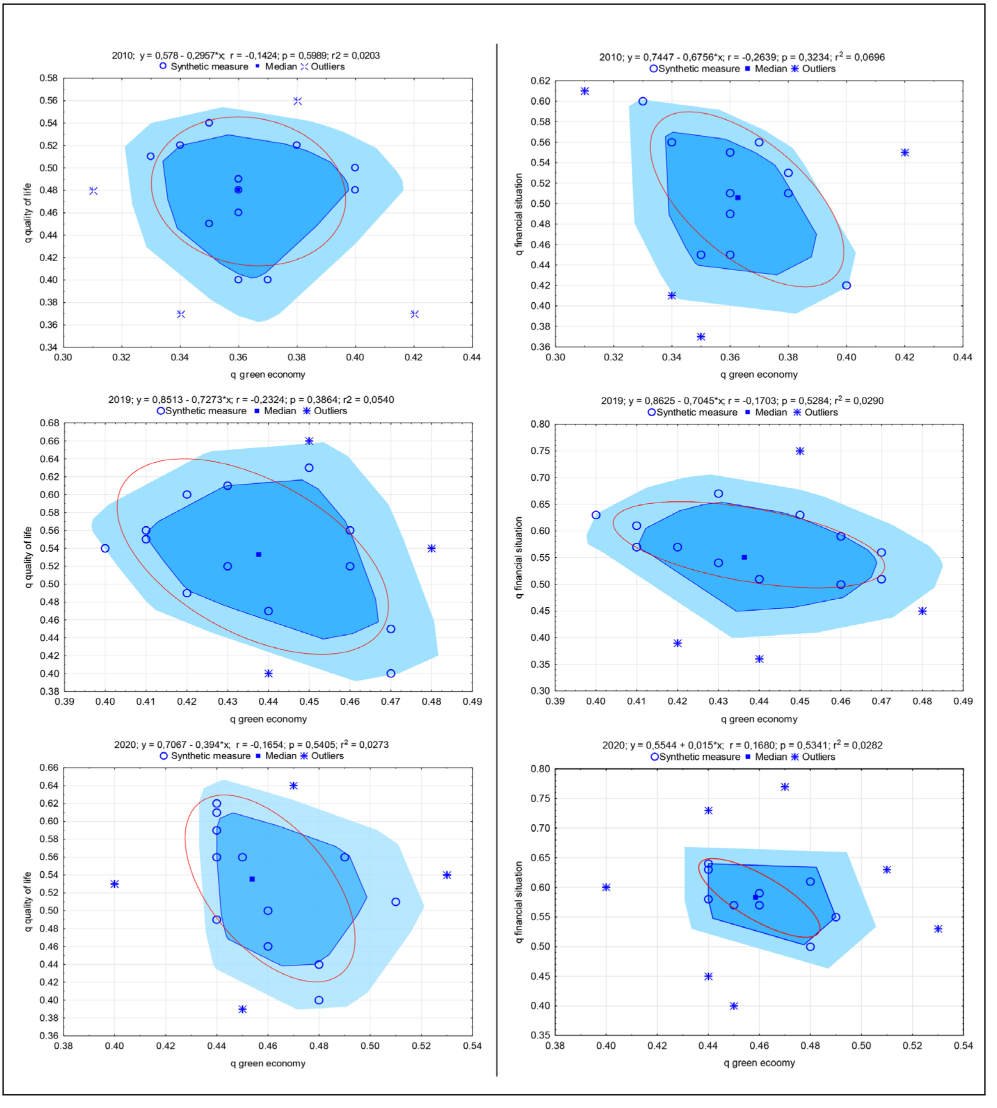

Fig. 4: Relation of green economy measure with quality of life and financial situation in Poland's voivodships (2010, 2019, 2020)

Source: own (based on the Statistic Poland data)

The findings of Spearman's rank correlation between the socio-economic factors that influence the green economy and its synthetic measure are displayed in Tab. 4. Spending on fixed assets for water management and environmental protection in 2010 had a positive impact on the indicator (0.502), the proportion of legally protected areas within the entire area (0.426), electricity production from renewable sources (0.349), and negatively shaped by the financial situation (−0.234), the share of active landfills in the total area (−0.238), electricity consumption (rural areas; −0.273), and the share of selectively collected waste in total waste (−0.306). Provinces that struggled with more waste and higher levels of energy consumption were less

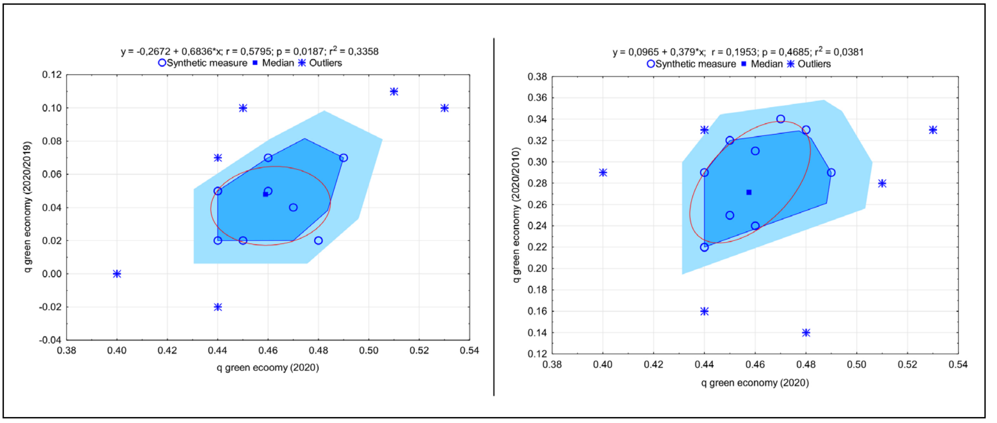

Fig. 5: **Relationship between green economy measure and relative changes (2020/2019, 2020/2010) in Poland's Voivodeships**

Source: own study based on the Statistic Poland data

Tab. 4: **Results of the synthetic measure of green economy's Spearman's range correlation with socio-economic indicators in Polish provinces (2010, 2019, 2020)**

Variables	2010	2019	2020
q quality of life	−0.063	−0.240	−0.269
q financial situation	−0.234	−0.290	−0.192
Expenditure on health care	0.248	0.395	0.399
Spending on waste management	−0.012	−0.213	−0.092
Expenditure on fixed assets for environmental protection and water management	0.502	−0.466	−0.293
Electricity usage in rural areasconsumption (rural areas)	−0.273	−0.035	0.048
Overall electricity generation	−0.070	0.167	0.344
Electricity production from renewable sources	0.349	0.691	0.537
Proportion of agricultural land in total area	−0.189	0.040	0.201
Proportion of forests in the total area	0.227	−0.018	−0.129
Proportion of legally protected areas in the total area	0.426	0.112	0.127
Proportion of ecological species in the total area	0.244	0.384	0.302
Proportion of active landfills in the total area	−0.238	−0.206	0.032
Proportion of selectively collected waste in total waste	−0.306	−0.305	−0.344

Note: Correlation coefficients are significant with $p < 0.05$.

Source: own (based on Statistic Poland data) effective in implementing the green economy. In 2020, renewable electricity generation (0.537), healthcare expenditure (0.399), total electricity generation (0.344), and the financial situation (−0.192), quality of life (−0.269), expenditure on environmental and water management fixed assets (−0.293), and the share of selectively collected waste in total waste (−0.344) were respectively ranked. This indicates challenges in waste management, which may have a diminishing effect on the effectiveness of the green economy. Spearman's rank correlation results for 2010 and 2020 show that some social and economic variables have a lasting impact on the development of the green economy in Poland, but the correlations vary with the time context. The correlation values indicate the need for further development of policies that integrate environmental issues with infrastructure development and improvement of the quality of life and financial situation of the provinces.

In order to accelerate Poland's transformation towards a green economy, it is recommended to strengthen regional policies that integrate environmental protection with the development of green infrastructure and the improvement of quality of life. Particular attention should be paid to regions with lower values of the synthetic green economy measure, such as Świętokrzyskie, Wielkopolskie, or Lubuskie, by increasing investments in green infrastructure, renewable energy sources, and effective waste management. In addition, it is necessary to combine spending on environmental protection with improvements in the financial situation and quality of life of residents in order to promote dynamic development. Regions with higher synthetic measures, such as Pomorskie or Kujawsko-Pomorskie, can play a leading role by sharing their experiences and best practices, which will help to reduce polarization between provinces and improve the efficiency of actions at the national level.

3.2 Discussion

In Poland, polarization is evident with regard to the green economy. The local Moran I statistics shows growing disparities between provinces in the implementation of green economy policies. An increase in the value of the synthetic measure of the green economy and a decrease in the coefficient of variation indicate progress but also the need for further action to reduce disparities in this area. Positive values (Zachodniopomorskie, Małopolskie, Mazowieckie, Opolskie, Podkarpackie) indicate a greater concentration and consistency of pro-environmental activities in some voivodeships, which may indicate better environmental management. On the other hand, negative values (Świętokrzyskie, Wielkopolskie, Lubuskie, Dolnośląskie, Kujawsko-Pomorskie) indicate challenges related to the integration of environmental actions in other regions, which may require more coordinated action at the local and regional level.

Dependence on coal has shaped the economies of many regions for many years, and this has had a significant impact on the pace of adaptation to the green economy, mainly due to structural, social, and economic conditions. These transitions require time, investment, and public policy support to be implemented in a sustainable and equitable manner. Provinces with higher spending on health care may also have higher spending on waste management as part of a comprehensive sustainable development policy in which citizens' health and waste management are interlinked. Provinces with higher spending on health care may also have higher spending on waste management as part of a comprehensive sustainable development policy in which citizens' health and waste management are interlinked.

The indicators used in the study take into account a number of variables of key importance for the green economy at the provincial level, including expenditure on health care, waste management, and investment in fixed assets for environmental protection and water management; electricity consumption in rural areas; electricity production from renewable sources; agricultural land; forests; or legally protected areas. These indicators allow an overall assessment of the development of the green economy in different regions of Poland and make it possible to compare the results in terms of the effectiveness of pro-environmental policies.

The evaluation of the polarization and clustering of the green economy in the Polish voivodeships was made feasible by the synthetic measure of the green economy and the Moran autocorrelation measures computed on this basis. The evaluation was predicated on factors pertaining to waste levels, natural capital, state policy, socio-economic issues, and environmental conditions (Tab. 1). The availability of empirical data gathered at a particular administrative level affects how the green economy is measured. This article's methodical methodology can broaden our understanding of GE shifts at the regional level. Since it has so many definitions and facets, it is challenging to define the notion of GE. The challenge, as stated by Lukas (2015), is figuring out what components contribute to GE. Developing nations incur significant costs during the switch to GE.

The authors' methodology for their analysis involved selecting a variety of metrics that, in their opinion, accurately represented the green economy (Tab. 1). This strategy is used and quite frequent (OECD, UNEP). The main goal of this strategy is to identify metrics that accurately capture the interplay between the environment and the economy or society in the studied region. It appears that the question of regional GE difference is the most significant topic in the field of study being conducted. This issue is related to the analysis of the consistency or lack thereof of the application of sustainable development.

In the context of Poland, a key issue remains the analysis of regional differences in the implementation of green economy objectives. These differences, which are the result of local conditions, are of great importance for assessing the coherence, or rather the lack of it, in the implementation of sustainable development policy in the country. In particular, the heterogeneity of the results of the analysis of the synthetic measure of the green economy between provinces indicates the need for further research into the factors that shape these differences, such as the specifics of the regional economy, natural resources, the level of urbanization, or the effectiveness of the implementation of public policies. Thus, the issue of regional differences in the green economy not only highlights the importance of local conditions but also challenges politicians and policymakers to take these differences into account when designing green policies. However, as Wyszkowska and Artemiuk (2016) point out, this requires taking actions that include the sustainable use of natural capital, maintaining the capacity of ecosystems to provide certain services, and ensuring good environmental quality without negative impacts on the health and livelihoods of citizens. These actions should make it possible to reconcile economic growth with environmental concerns.

Li et al. (2022) state that GE acknowledges shifts in consumer awareness and investments in renewable energy as ways it supports sustainable development and environmental protection. GE needs to acknowledge the limitations imposed by the environment and the economy, including the degree and composition of the endogenous territorial division. By doing so, the steps taken should be optimized, and resource conservation should take precedence over environmental deterioration. D'Amato and Korhonen (2021) have demonstrated that natural resources are a crucial component of economic and social progress. However, inadequate resource usage has resulted in resource depletion and environmental degradation, endangering both human welfare and the ecosystem. Additionally, GE helps authorities at the local, regional, national, and international levels identify sustainability concerns and operationalize solutions.

Houssam et al. (2023) claim that in addition to the effects of climate change and the fuel, food, and financial crises, the depletion of natural resources, the destruction of ecosystems, and the loss of biodiversity are driving national and regional authorities to find practical solutions for the problems of ecological constraint and biodiversity. Various entities are forced to take action to improve the efficiency of environmental resources' usage in the manufacturing process due to the systematic growth in their consumption, particularly non-renewable resources. As Wyszkowska (2016) notes, it is beneficial to have a permanent green economic ocean. It ought to offer data on which actors can base their decisions.

According to Dace et al. (2024), a circular bioeconomy must replace a linear fossil fuel-based economy. There are several obstacles standing in the way of the shift to a sustainable closed-loop bioeconomy, including technological, social, political, and structural ones. The externalities to the environment might impede green growth if producers and/or consumers are encouraged to pollute more, as noted by Sarkodie et al. (2024). In the face of global environmental changes, and in the context of ensuring food security, there is a growing need for the economy to switch to renewable energy sources and move towards sustainable production and consumption patterns. Shifting to a more sustainable economy through more efficient use and effective management of biological resources can contribute to reducing waste, pollution, and climate change while reducing pressure on fossil resources (Luczka, 2018).

However, the environmental context and the need to develop technological innovations that will enable the transformation of the EU economy towards a low-carbon and climate-neutral economy should not be forgotten. From the perspective of the European Union, it is crucial to achieve climate neutrality and to fully implement a model of sustainable development in which social and environmental issues are important alongside economic performance. As a result, the development of technological innovation in the energy sector is becoming increasingly important (Tomala & Urbaniec, 2024). The effectiveness of the green economy is often revealed through the characteristics of regional heterogeneity in space, meaning that different regions may have different levels of sophistication and effectiveness of green policies. However, regardless of the specificities of regions, the green economy, as a holistic strategy to address environmental, social, and economic issues, plays a key role in sustainable development. From a development perspective, reducing the use of natural resources becomes a necessary step that will contribute to improving environmental conditions. Such changes not only support environmental protection but also promote innovative approaches to resource management that can lead to more sustainable and resilient economic development in the long term. Implementing the green economy in different regions therefore requires appropriate policies and investments that take into account local needs and potential and motivate action to protect the environment and care for future generations.

Conclusions

The results of the research, which is based on the spatial autocorrelation of the green economy and takes into account variables such as expenditure on health care, waste management, investment in environmental protection, electricity production (including from renewable sources), and management of natural resources (e.g., agricultural land, forests, protected areas), are important because they provide a comprehensive picture of the state of the green economy in individual Polish provinces. This makes it possible to identify areas that are making progress in implementing green policies and those that still face challenges in this regard. There is a significant positive spatial autocorrelation of green economy indicators in individual regions of Poland, indicating that regions with high green economy performance tend to cluster together. Voivodships with a historically high dependence on coal show lower green economy growth rates than others. Expenditure on health care and waste management are positively autocorrelated, indicating the mutual influence of these two areas on green economy growth.

Local Moran I statistics show increasing disparities between provinces in the implementation of green economy policies. Although we see progress in the synthetic measure of the green economy and a reduction in variability, action is still needed to reduce disparities. Positive values (e.g., in Zachodniopomorskie, Małopolskie, Mazowieckie) indicate greater consistency in green policies, while negative values (e.g., in Świętokrzyskie, Wielkopolskie, Lubuskie) indicate challenges in integrating green policies in these regions.

The green economy's efficacy frequently demonstrates characteristics of regional heterogeneity in space. A holistic strategy for addressing environmental, social, and economic issues is the "green economy." It calls for the prudent use of resources, a decrease in waste and pollution, the protection of biodiversity, the encouragement of innovation, and the effective use of available resources.

Energy and resource efficiency should increase throughout regions. The green economy can serve as a foundation for policy development, investment (especially in clean technology), waste management, renewable energy, transportation, and renewable energy. Green economy initiatives by regional governments ought to encourage advancements in sustainability as well as increased efficiency. Reducing the usage of natural resources is imperative at this point in development, as it will contribute to better environmental conditions.

With the help of autocorrelation analysis and a synthetic measure, the given model enables comparisons between units and the display of changes in the studied phenomenon over time in the studied area. By using the spatial autocorrelation method, one may determine which parts of voivodships have comparable values of the phenomenon under study and can also observe the impact of geographical interdependence between neighboring voivodships. One benefit of spatial autocorrelation is that it may be used to describe the spatial differentiation of the area under analysis. This can be done by using maps and specific values of local and global statistics. It is a helpful tool in the study of regional development since it enables a deeper understanding of the dependencies that already exist. In this context, spatial autocorrelation helps to isolate key areas that may show common characteristics or development trends, which is of great importance in the analysis of regional differences and cohesion.

Systematic studies on the green economy should give regional authorities the knowledge they need to evaluate and adjust the actions taken in connection with the examined field (such as the green economy, green development), taking into account any discrepancies that may exist between units. The findings will also provide direction for potential steps to lessen polarization within the GE amongst voivodships and enable comparisons between voivodships (while preserving the same technique and variables). The study methodology can be expanded to take into account new areas that may affect the level of GE, such as demography, ecology, infrastructure, and entrepreneurship. It may also involve examining the direction and strength of outlier variables' influence on the primary criterion, as well as exploring new methods for evaluating autocorrelation. New diagnostic variables can be added, and analyses can be conducted over longer time periods.

The research is limited by the data's accessibility within official statistical frameworks, its comparability, evolving laws, shifting socioeconomic conditions, and chance occurrences. Specifically, the selection of years (2010, 2019, and 2020) for the analysis, while guided by significant economic events, such as post-crisis recovery and the COVID-19 pandemic, limits the ability to observe trends over a continuous timeline. Including data from intermediate years might have provided a more nuanced understanding of the progression and challenges of the green economy over time. Also, the reliance on certain regional-level data may not fully capture the complexities of local-level economic and environmental interactions. This limitation might result in an oversimplification of how specific factors, such as waste management expenditure or renewable energy generation, directly affect green economy performance at more localized levels.

Future research should aim to address these limitations by incorporating more continuous time-series data to offer a clearer view of green economy trends over time. Additionally, further research could focus on cross-country comparisons or smaller geographical scales to provide more localized insights into the factors driving green economy growth. Research on a larger sample of diagnostic variables to better understand the determinants of green economy development and longer timeframes will enable capturing dynamic changes, forecasting trends and better planning of regional development strategies. It would also be valuable to explore the long-term effects of significant disruptions, such as the COVID-19 pandemic, on the green economy in more detail.

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