

Article

Socio-Economic Resilience of Poland's Lignite Regions

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Abstract: The article is seeking to analyse the coal transition in three Polish lignite regions as part of the scientific discussion on a just transition, which is a big challenge, especially in the regions and countries dependent on their own coal deposits as the main source of energy. Polish lignite mines are now entering the phase-out of coal, which results from implementing the assumptions of the Green Deal and the Paris climate agreement. The article answers the following question: what is the socio-economic resilience of coal regions in the context of the projected closure of mines in the coming years? The empirical analyses are based on secondary statistical data. The analysis and comparison of basic statistical data, i.e., the level of employment and lignite extraction in three lignite regions in the period from the end of the Second World War to 2017, allowed the authors to determine the phases of the adaptive cycle in which the individual regions are. In the second part of the study, the indicator evaluation method was used in order to calculate the Socio-Economic Resilience Index for individual areas (poviats) included in the coal regions, which made it possible to assess the current resilience and its intra-regional differentiation. The obtained results, which indicate that the regions under analysis are in different phases of the adaptive cycle and reveal their territorial heterogeneity, allow us to assume that the possibilities of a just energy transition of regions depend on the diversity of local conditions and resources, emphasising at the same time the territorial dimension of the issue of the energy transition.



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Keywords: coal phase-out; just transition; socio-economic resilience; adaptive cycle model; lignite mining

1. Introduction

Poland is one of the leading producers of lignite both in Europe and in the world. According to Eurostat data, in 2020, lignite extraction in Poland amounted to 46.1 million tonnes, which accounted for nearly 20% of the EU's production (second place among the EU countries). The largest lignite producer is Germany, with extraction at the level of 107.4 million tonnes, i.e., over 40% in the EU.

Lignite is one of the most important raw materials exploited in Poland. The geological balance resources in the developed deposits amounted to 1110.62 million tonnes at the end of 2020 and accounted for 4.79% of the total geological balance resources. At that time, 65% of energy in Poland was generated in hard coal and lignite-fired power plants [1]. Eurostat data show that the share of lignite in gross electricity production in 2020 was over 24%, whereas, in 2011, it amounted to 32%. This shows a decrease of 8% over the last decade. Despite the fact that the share of available capacity of lignite-fired power plants has been decreasing in recent years, the importance of this raw material for the energy sector still remains high. Lignite deposits in Poland are located in the western and central part of the country, while their extraction in 2020 was carried out in five open-cast mines: Bełchatów, Turów, Adamów, Konin, and Sieniawa [2]. Lignite regions have developed over the decades around the largest (The aggregate data for 2017 indicate that the Bełchatów mine was the largest coal producer—42.6 million tonnes (70% of all production in Poland, which was then around 61.2 million tonnes). The following mines were: Konin, Turów, and

Adamów (14%, 11%, and 5%, respectively). The extraction of coal in the Sieniawa mine amounted to approximately 100 thousand tonnes, which is a marginal value compared to other mines. Little exploitation, and hence limited employment, translated into the local, and not regional character of this mine). mines and accompanying power plants and are now on the verge of the phase-out of coal resulting from the Paris climate agreement.

The formal framework for the phase-out of coal of lignite regions in Poland has been set out in national and European strategic documents. At the national level, the key document in this regard is the “Energy Policy of Poland until 2040” (PEP2040) developed by the Ministry of Climate and Environment in 2021. It defines the framework for the energy transformation in Poland by adjusting the national economy to the EU regulations related to the climate and energy goals for 2030, the European Green Deal, the economic recovery plan after the COVID pandemic and the pursuit of climate neutrality in line with national capabilities, as a contribution to the implementation of the Paris Agreement. PEP2040 is consistent with the vision of the EU development contained in “The Green Deal” adopted by the European Council at the end of 2019. An important pillar of the PEP2040 implementation is a just transition, which “means providing new development opportunities for the regions and communities most negatively affected by the low-emission energy transition, while creating new jobs and building new branches of industry that participate in the energy sector transition” [3]. The Just Transition Mechanism is a tool for implementing a just transition, which is designed to support coal regions in the process of transition and mitigate its socio-economic impact through the Just Transition Fund (part of the Cohesion Policy). The EU countries wishing to use the resources from the Just Transition Fund have been obliged to prepare Territorial Just Transition Plans (TJTPs) for their coal regions. In Poland, seven Just Transition regions have been designated, three of which (the Zgorzelec sub-region, the Eastern Wielkopolska region and the Łódź region) cover lignite mining areas, and the others have been created around the hard coal basins.

A just transition is a huge challenge in every respect, especially in the regions and countries which are energy dependent on their own coal deposits [4–6], which translates into relatively high scientific interest in this subject in various problematic and methodological contexts [7,8]. Research on a just transition, otherwise defined as sustainable transition, available in the world literature presents a very diverse profile of analytical possibilities, encompassing various levels of the process, including the technical ones [9,10], and different methodological approaches [11]: from processual, to structural, to cultural and social [12,13]. The discussion about the energy transformation in Poland is multi-faceted, highlighting in the first place the obstacles resulting from the structure of energy production, the quality of infrastructure as well as the political and social issues [14–16]. Among the many detailed issues emphasising the importance of a given factor, researchers also focus on legal issues, related to both the national and local law, especially regarding the possibility of creating infrastructure generating energy from renewable sources [17–19]. In addition, the diversity of local conditions and resources also draws the attention of researchers to the territorial dimension of the issue of energy transformation, particularly in connection with the search for the correctness of spatial differentiation in the social and economic subsystem related to energy production and consumption [20,21].

In light of the above, it may be assumed that the possibilities of a just energy transition of regions depend on the diversity of local conditions and resources. Therefore, it is justified to emphasise the role of the geographical factor, i.e., specific conditions resulting, on the one hand, from the location of production and services, and on the other hand, an attempt to comprehensively explain the process of changes from the point of view of the nature of the environment, region and place [22–25]. Thus, the aim of this article is to analyse the coal transition in three Polish lignite regions in the context of their socio-economic resilience, taking into consideration their internal diversity. The concept of resilience has already been used in the coal transition research, including two lignite mining regions in Germany, providing useful insights into how regional economies withstand severe disruptions [26]. The research presented in this article has been extended to encompass the analysis of the

socio-economic resilience index in the context of its diversity within the lignite regions. The research hypothesis of this paper is that the three Polish lignite regions under analysis may have different resilience to the planned closure of mines and that the areas of transition are not territorially homogeneous. The authors have been able to explain the reasons for this heterogeneity in relation to the varying nature of the settlement systems which make up the lignite regions.

Due to their origin and structure, Polish lignite regions participating in the just transition have their own specificity that distinguishes them from the old “traditional” coal basins. Therefore, Section 2 of the article provides a detailed overview of the regions under analysis. Section 3 presents the research methodology, i.e., the method of adapting the concept of resilience to the analysis of the ongoing sustainability transitions of Polish lignite mining regions. Next, the results of the study are presented: a comparative case study of the Polish lignite regions in the context of their regional economic resilience—in Section 4.1 and the socio-economic resilience index analysis—in Section 4.2. The article ends with a discussion of the obtained results and conclusions.

2. Overview of the Study Regions

As mentioned above, in recent years, five lignite mines have been operating in Poland around which three lignite regions have developed. The delimitation of these regions for the purposes of this study relates directly to the boundaries of the transition areas indicated in the respective TJTPs. The boundaries of the regions designated in this way include areas that are predicted to be most affected by the negative effects of the transition. From the point of view of the objectives set out in this article (assessment of socio-economic resilience), the adoption of a bottom-up delimitation by widely understood communities of the regions seems justified. The lignite regions delineated in the TJTPs vary widely in terms of their area and population. However, one thing which they do have in common is their place in the settlement structure of the country, i.e., their location on the regional periphery. At this point, it is worth noting that these relatively young industrial districts formed on the regional periphery in the 1970s and 1980s will undergo a completely different transition than the old coal basins, which were the basis for the formation of complex systems of urban agglomerations [27–29]. We should keep in mind that industrial districts shaped as a result of the development of lignite deposits in Poland after the Second World War were often integrated into areas with extensive spatial development and areas with predominantly agricultural functions and other rural or small-town activities. It was a kind of a revolution for those areas, not only economic, but also social, which fundamentally changed the living and working conditions and the model of spatial movements [30].

The Zgorzelec Lignite Region is located in the southwestern part of the country and covers the entire Zgorzelec powiat (Powiats constitute an intermediate level of the administrative division of Poland, between voivodships (regions—NUTS2 level) and gminas (local administrative units—LAU). Groups of powiats correspond to the NUTS3 level according to the NUTS classification UE). This powiat is located in the western part of Lower Silesia (Dolny Śląsk), at the meeting point of three countries: Poland—Czech Republic—Germany (Figure 1). The area of the Turów Lignite Region is about 840 km² and covers 7 gminas: Zgorzelec, Węgliniec, Sulików, Bogatynia, Pieńsk, and the cities of Zawidów and Zgorzelec. The region is inhabited by over 88,000 residents.

The Eastern Wielkopolska Lignite Region is located in the central part of the country, east of Poznań. The region includes five powiats of the Konin subregion: the Słupca, Koło, Turek, Konin powiats, and the city of Konin. The area of the region is over 4.4 thousand km² and is inhabited by over 430,000 people.

The Łódź Lignite Region includes eight powiats located on the southern periphery of the Łódź region: the Wieluń, Sieradz, Łask, Bełchatów, Piotrków, Radomsko, Pajęczno powiats and the city of Piotrków Trybunalski. It is the largest of the analysed regions, with an area of 7.7 thousand km² inhabited by 680,000 people.

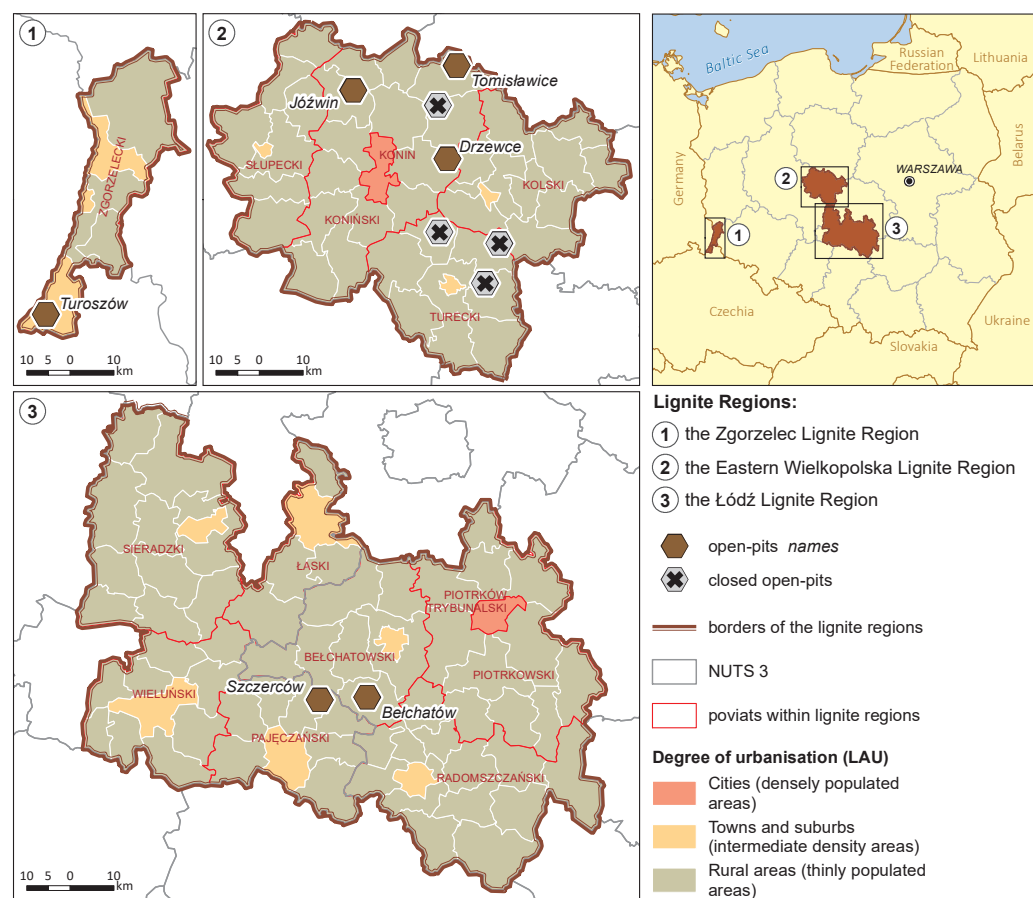


Figure 1. The location and administrative structure of the regions under analysis.

The Zgorzelec Lignite Region, which is the smallest region, has the highest population density (over 105 people/km²) and the highest level of urbanisation (based on Eurostat data from 2021), despite the fact that there are no big cities in the region. The largest towns are Zgorzelec and Bogatynia (with 29.8 and 22.6 thousand people, respectively). In Eastern Wielkopolska, the average population density is 97 people/km², and the main city is Konin (72.5 thousand people), located in the central part of the region. In the Łódź Lignite Region, the population density is the lowest (below 88 people/km²), as agricultural areas prevail in that region. The main city of the region is Piotrków Trybunalski (72.2 thousand people), located in its eastern part, and the main towns are Bełchatów (56.4 thousand people), Radomsko (45.4 thousand people) and Sieradz (41.4 thousand people).

3. Theoretical and Methodological Concepts

3.1. Resilience Theory

As has been said in the Introduction, the starting point for this study is the analysis carried out by Stognief et al. [26] on the economic resilience of German lignite regions, which was conducted from the perspective of regional economic resilience. The results obtained by the authors are meaningful, and the proposed research scheme is applicable in this particular case. The work of Stognief et al. which we refer to was preceded by other regional studies that utilised the concept of resilience. The very concept of resilience, as well as its opposite—vulnerability, originated in natural sciences (ecology) in the 1970s [31] and was relatively quickly adopted in social sciences [32–34] and later in economic geography [35,36]. There are numerous scientific studies which discuss the development of this concept in detail and review the achievements in various research contexts, including the works of Cretney, Lintz et al., or Pendall et al. [37–40]. From the point of view of the objectives set out in this article, it is justified not only to discuss the

development and various applications of this concept, but also to explain in more detail the context of the concept of resilience in economic geography and regional analyses. This methodological approach has been used since the concept of resilience fits into cyclical thinking, which indicates the existence of economic cycles with alternating upward and downward movements separated by periods of recession and prosperity. However, unlike the twentieth-century theories, especially evolutionism which may be found in the works of such authors as Kondratiev, Braudel or Schumpeter, the use of the concept of resilience makes it possible to analyse the dynamics of the region, as it goes beyond the economic and political behaviour of the system and takes into account the social dimension [41].

Initially, Holling defined ecological resilience as “the ability of a system to absorb disturbance, before resorting to a shift in system state, through changing variables and processes that control behaviour” [31]. In this approach, Holling built the ecological model of ‘adaptive cycles’, assuming the existence of one equilibrium which the system returns to [42,43]. Holling’s adaptive cycle is a heuristic model which allows us to explain the transformations of complex systems by understanding their structures and patterns [41]. Subsequent research has shown that, with regard to complex territorial socio-economic systems, i.e., regions, it is more useful to understand resilience based on multiple equilibria models, or from the evolutionary perspective within economic geography—in the context of constantly changing non-equilibrium systems [36,39,44]. The evolutionary approach assumes that “resilience is considered as an ongoing process rather than a recovery to a (pre-existing or new) stable equilibrium state” [36].

Stognief et al. “translated” the ecological model of adaptive cycles into the language of evolutionary economic geography by identifying the phases of the cycle and characterising the model parameters in relation to the economic situation of the regions under analysis [26]. This research draws on those achievements, yet due to the limitations in data availability, slightly different indicators have been analysed for Polish coal regions. The figure below shows the individual phases of the adaptive cycle in relation to the changing values of the model parameters: potential, connectedness and resilience, which determine the reaction of the system (region) to disturbances. Potential is understood as the wealth or resources of a region that determine the range of possible future options for the return to equilibrium. Connectedness means the internal controllability of the system, reflecting the degree of stiffness of control variables and processes, while resilience is the opposite of vulnerability to changes, determining the adaptive capacity of a region. The reorganisation phase is characterised by innovation and reconstruction. During this period, the region has high potential, low connectedness, and increasing resilience (Figure 2). There is a relatively quick transition to the exploitation phase, characterised by low potential, as resources are used to provide growth and expansion of possibilities. In this long phase, connectedness increases and high resilience is achieved. In the conservation phase, the region achieves stability due to its very high potential and increasing rigidity, and its resilience begins to decline. The last phase of the cycle is the release phase characterised as decline and destruction, when the region reaches very low potential. In response to the disturbance, high connectedness begins to decrease, and low resilience starts to increase [26,42].

In the course of developing the concept of the adaptive cycle, especially in relation to social and economic regions, pathological states of the system have also been identified apart from phases. In two of the states, a poverty trap and a rigidity trap identified by Holling are obtained respectively: very low and very high values of potential, connectedness and resilience. In addition, a dissolution trap or lock-in trap has been identified when low potential occurs at high values of connectedness and resilience, and the reverse situation—high potential with low values of connectedness and resilience, defined as a vagabond trap [41,45,46].

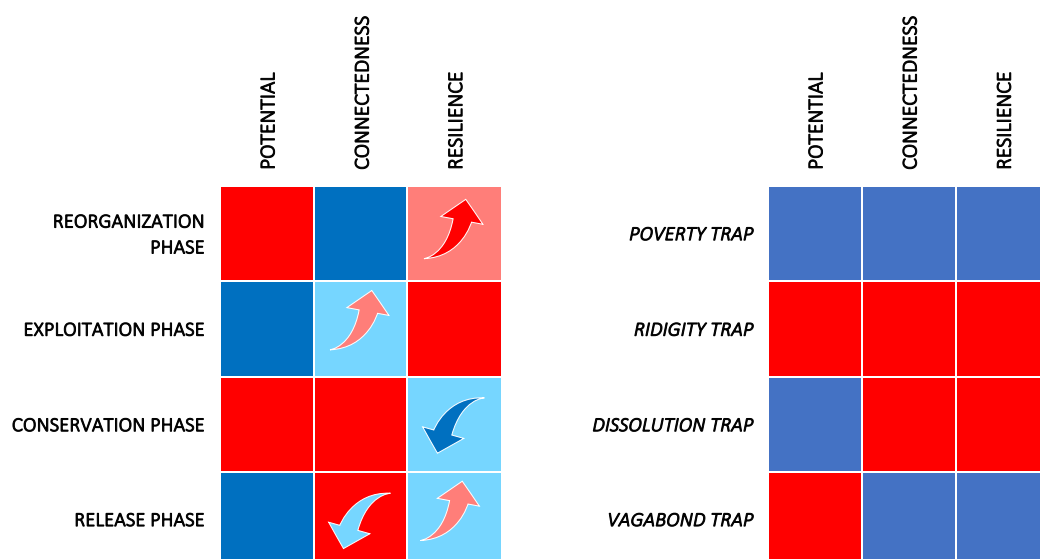


Figure 2. Four phases and pathological states of the adaptive cycle.

3.2. Materials and Methods

The evolutionary perspective allows us to look at the resilience of coal regions to the impending withdrawal from coal and the possibilities of further development through the prism of adaptive cycles, by determining which phase a given region is in. For this purpose, the authors have analysed and compared basic statistical data on the level of employment and lignite mining in three lignite regions in the period from the end of the Second World War to 2017, using the data available in a report by Zbigniew Kasztelewicz (Data on the level of coal extraction and employment in lignite mines presented in the Report on the condition of the lignite industry in Poland and Germany [47] were prepared by the author on the basis of data from mines and they constitute the only comparable and available data for these mines throughout the entire period of their operation) [47]. The context for this part of the analysis consisted in determining the main events and factors influencing the changes in the level of mining and employment, which were identified on the basis of a review of the scientific literature, reports and monographs on mines and lignite mining regions in Poland. This research approach was more qualitative in nature.

In the second part of the study, a quantitative perspective was adopted to assess the current resilience and its intra-regional differentiation. Using the indicator evaluation method, the Socio-Economic Resilience Index (SERes Index) was calculated for individual areas (poviats) included in the coal regions. The construction of the Socio-Economic Resilience Index (SERes Index) was based on the procedures for building similar indicators described in the literature [48–51]. In order to build the SERes Index, the authors selected variables made available at the poviats level by Statistics Poland, i.e., variables characterising the regions in economic and social terms in 2020 and corresponding to the parameters of the adaptive cycle model (Table 1): GDP *per capita* (GDP), revenue–share in income from taxes *per capita* (RIT), registered unemployment rate (RUR), beneficiaries of social assistance per 10,000 population (BSA), median age of population (MAP), and net migration per 10,000 population (NMP). The selection of specific indicators referred to previously conducted research [26,52,53], but it was improved by the possibility of obtaining publicly available data at the poviats level—below NUTS 3 (The NUTS (Nomenclature of Territorial Units for Statistics) classification is commonly used in the European Union countries as a system of statistical territorial units covering three levels: NUTS 1—macroregions, NUTS 2—regions and NUTS 3—subregions).

Table 1. Evaluation index system of socio-economic resilience in Poland's lignite regions.

Domains of Resilience	Indicator's Code	Unit	Adaptive Cycle Parameters	Property
Economic	GDP	PLN	Potential	Positive
Economic	RIT	PLN	Potential	Negative
Economic	RUR	%	Connectedness	Negative
Social	BSA	Person	Connectedness	Negative
Social	MAP	Years	Resilience	Negative
Social	NMP	Person	Resilience	Positive

As mentioned above, one of the three parameters of the adaptive cycle is potential, related to the range of possible options available for future responses of the system to the necessity to change, and thus it determines the resources of the system. In this study—in relation to the lignite regions—the potential is represented by the amount of GDP *per capita* and the own revenue of local government units derived from taxes—determined and collected on the basis of separate acts. Although Statistics Poland does not provide data on the amount of GDP at the poviats level—the data are made available for higher-level units, i.e., subregions and regions, in research practice, data estimated using the wage fund method are adopted for poviats [52]. This method is based on the assumption that the value of manufactured production should be related to the remuneration received by the factors that create it. Therefore, the GDP value is distributed among poviats adequately to the employee wage fund. The calculated product of the average gross salary in a given poviat and the number of people working there (data provided at the poviat level by Statistics Poland) determined the proportion of the GDP divided into poviats belonging to this subregion [54]. The second indicator determining the economic potential of the lignite regions is the revenue of local government units related to the operation of open-cast mines within their areas. Following Ptak and Kasztelewicz [55], coal mines in Poland incur about 20 different fees and levies to the state budget and local governments in which they operate. In the case of lignite open-cast mines, taxes, charges and penalties payable to gminas (including mining fees) amount to an average of about 20% of all fees. For example, in 2011, they amounted to over PLN 230 million. There are no available and comparable data on the amounts of money that lignite mines contribute to gminas' budgets, but the analysis of the structure of revenues of local government units provided by *Statistics Poland* allows us to conclude that revenues from mines are included in the budget category of own revenues, i.e., income tax determined and levied on the basis of separate acts (including the Polish Geological and Mining Law, which regulates issues concerning the mining fee).

The second parameter under analysis is connectedness, which defines the degree of flexibility and rigidity of the system. In the context of the phase-out of coal in coal basins, their sensitivity (or lack of it) to the closure of mines may be understood, among other things, from the assessment of the labour market and the level of selected social problems in a given region. Therefore, the construction of the SERes Index included the unemployment rate, the low level of which indicates lack of structural unemployment and allows us to suspect that the local labour market will quickly absorb people who would normally work in a mine, but will not find employment at the maintenance works during the phase-out process. The second connectedness indicator is the number of beneficiaries of environmental social welfare (per 10,000 people in a poviat), the low value of which reflects a small scale of social problems resulting from unemployment, poverty or homelessness. The last parameter of the adaptive cycle is resilience, which determines the adaptive capacity of a region. In other words, it is a measure of the system's ability to deal with vulnerability. With regard to coal regions, adaptive capacity is built on available social capital, determined on the basis of the median age of the inhabitants, which shows how young the society is in a given poviat and the migration balance. The migration balance (estimated per 10,000 people in a poviat) determines the attractiveness of the poviat for its inhabitants, but—taking into account the high mobility of mainly young people—it also translates into the quality of local labour resources, which will have an influence on how a

given poviats cope with the energy transformation. It is expected that younger societies will be less sensitive to the closure of mines due to greater capacity for innovation. The construction procedure for the SERes Index refers to the scientific achievements already existing in this field and covers three main stages: standardisation of selected variables, correlation analysis in order to detect problems related to multicollinearity between the variables, and, in the last step, index construction [56–60]. In order to compare the variables expressed in different units, standardisation of indicators was carried out using the min-max transformation method for the range (0–1), assuming the minimum and maximum values of a given variable. Additionally, the variables describing negative phenomena (RIT, RUR, BSA, MAP) were negatively normalised from 0 to 1, while the positive variables (GDP and NMP) were positively normalised from 0 to 1. Summary statistics for the indicators are presented in Table 2. The transformed indices were added together and the mean of the sub-indices corresponding to the adaptive cycle parameters was calculated: Potential Sub-Index (PSI), Connectedness Sub-Index (CSI) and Resilience Sub-Index (RSI). The proposed Socio-Economic Resilience Index was built from six variables which, in relation to the adaptive cycle parameters, have a proportional share in the composite indicator, and therefore the weights of individual components are equal. Ultimately, the SERes Index value is the sum of the transformed PSI, CSI and RSI values that fall within the range (0–3).

Table 2. Summary statistics for the indicators included in the SERes Index.

Indicator	Mean	Standard Deviation	Min	Max
GDP	4251.93	2075.18	1511	10,287
RSIT	927.50	418.07	541.74	2030.20
RUR	6.51	1.45	4.60	9.70
BSA	452.14	82.78	308	574
MAP	42.03	1.46	39.70	45.10
NMP	−18.60	23.90	−70.44	21.49

The correctness of the selection of variables for the construction of the SERes Index is confirmed by their low inter-item correlation. The Pearson correlation coefficients for sub-indices range from 0.13 to 0.31 (Table 3). The SERes Index and its sub-indices were calculated for individual poviats, and their mean values for poviats were calculated for the Eastern Wielkopolska and Łódź regions.

Table 3. Correlation coefficients for the sub-indices.

	PSI	CSI	RSI
PSI	1.00		
CSI	0.16	1.00	
RSI	0.13	0.31	1.00

4. Results

4.1. Adaptive Cycles

The Turów mine was established in 1947, after the end of the Second World War, on the basis of the German Hirschfelde plant, which at the beginning of the 20th century extracted lignite using the open-cast method. Over the next decade, the mine was gradually taken over by Polish miners. In the initial period of its operation, half of the staff were Germans living on the other side of the border. This period may be described as the reorganisation phase (Figure 3), during which the mine was prepared for coal mining at the assumed level. The exploitation phase began at the end of the 1950s, when government decisions were made to build the “Kombinat Górniczo-Energetycznego na węgla brunatnym w Turosszowie” (Lignite Mining and Power Plant in Turosszów), which in those years was the largest energy investment of this type in Europe. Its construction

ended in 1965. The exploitation phase, characterised by intensive development of the mine and the surrounding region, changed into the conservation phase in the early 1970s. During this period, the mine developed steadily and produced on average from several to 20 million tons of coal per year, mainly for the needs of the 2000 MW Turów Power Plant. At the beginning of the 1990s, the company's modernisation program began, encompassing among other things the construction of new basic machines. This, in turn, was associated with increased employment on the one hand, but on the other, with a decrease in coal mining. At the beginning of the first decade of the 21st century, there were changes in the mine's ownership structure—the enterprise was commercialised and became part of the company, which also owns the largest lignite mine in Poland, i.e., the Bełchatów mine. The organisational changes in the mine and the fulfilment of the assumptions of Poland's energy policy indicate the entry into the release phase at the beginning of the second decade of the 21st century. During this period, there has been a steady decline in both employment and coal production. However, the extension in 2021 of the license for the extraction of lignite in the Turów mine until 2044, with the assumed production of around 10 million tons per year, may significantly extend the release phase and delay the commencement of the next reorganisation phase.

Due to the scattering of lignite deposits in Eastern Wielkopolska, there were two large multi-site open-cast mines operating in the region. The first mine in the region—"Konin", just like the Turów mine, was launched just after the Second World War on the basis of the existing infrastructure built initially for German plants. In the following years, more open-cast sites were launched in the Konin region and the "Konin" power plant was built, operating on the basis of lignite. The reorganisation phase also included the preparatory stage for the launch of the second mine in the region—"Adamów". Lignite deposits in the Turek powiat were discovered in the early 1950s during the search for crude oil. The balance resources of the discovered coal were estimated at 142 million tons, and as early as 1959 the decommissioning of the Adamów open-cast mine began [61]. The exploitation phase began at the turn of the 1950s and 1960s and was connected with a significant increase in employment and extraction in both mines, lasting several years. The completion of the construction of the "Pałnów" power plant in 1969, accompanying the "Adamów" mine, marked the beginning of the conservation phase, which was characterised by high coal production reaching nearly 20 million tons per year and large employment amounting to over 11.5 thousand people in both mines at the end of the 1980s. As in the case of the Turów mine, the release phase began in Eastern Wielkopolska at the end of the first decade of the 21st century. During this period, employment and lignite mining was gradually reduced in the existing sites, and no extraction was launched in new sites. A few years ago, the mines of Eastern Wielkopolska entered the reorganisation phase. In 2017, the Adamów power plant was closed. The accompanying mine exploited the remaining coal reserves for the needs of the remote Pałnów power plant for a few more years and, after exhausting its resources, it was closed at the beginning of 2021. Currently, the Konin mine is operating in the region, extracting coal from three open-cast sites, which are planned to be shut down until the end 2030, and the maintained Konin power plant has been undergoing gradual conversion to biomass for several years.

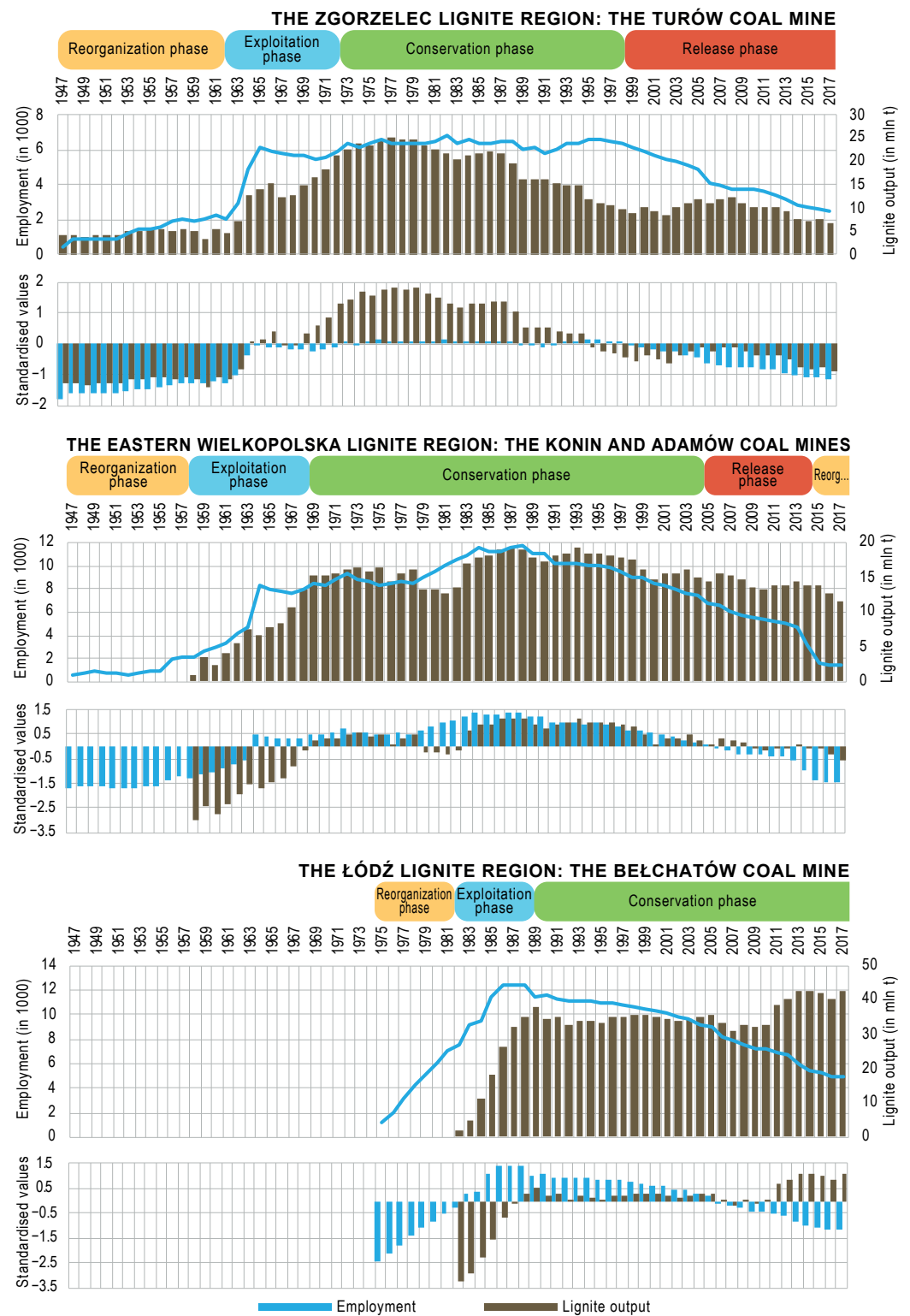


Figure 3. Adaptive cycles of Polish lignite regions in relation to employment and coal extraction in mines in the period between 1947 and 2017. (The colours indicate phases of the adaptive cycle: reorganization—orange; exploitation—blue; conservation—green; release—red).

The youngest and at the same time the largest lignite mine in Poland is located in the Łódź region, near Bełchatów. Coal deposits were discovered in this area at the end of 1960—as in the case of the Adamów mine—during the exploration of crude oil, but it was not until the beginning of 1975 that the State Enterprise Kopalnia Węgla Brunatnego

“Bełchatów” was established with an accompanying power plant [62,63]. The reason why the decision to start coal mining in the Bełchatów region was delayed was the fact that, in the mid-1960s, there was an excess of hard coal production in Western European countries, and the related collapse in the export of Polish coal, while striving to maintain a constant level of its extraction, which could pose a risk of unemployment in Upper Silesia (Górny Śląsk)—the main hard coal mining region in Poland. In turn, several years later, another external factor, i.e., the global energy crisis of 1973, highlighted the importance of energy based on domestic primary energy resources (it was then that the concepts of “energy security” and “energy sovereignty” were coined), which prompted the Polish authorities to decide to build a mine and a power plant in Bełchatów [64]. The reorganisation phase lasted several years during which the equipment was prepared and the deposit was drained. In the 1970s, the Bełchatów region was the construction site of the largest mining and energy complex in Poland. Apart from the mine and the power plant itself, social and housing facilities (recreation and leisure centres, housing estates) were built for the employees of the complex [65]. The exploitation phase began in the early-1980s: the extraction of coal and its use in the neighbouring power plant “Bełchatów I” began in 1981 [66]. Employment and coal mining increased significantly during this period. After nearly a decade, the region entered the conservation phase, which was characterised by a stable level of coal extraction (from 30 to 40 million tons a year) from the “Bełchatów” open-cast site and a relatively high level of employment. With time, slow decline in employment resulted from its systematic rationalisation, leading to an increase in productivity, and not from restrictions on the operation of the mine. Gradual depletion of the “Bełchatów” deposit resulted in the commencement of mining in the neighbouring site of “Szczerców” in 2009, which translated into record-high coal extraction in the Bełchatów mine in the following years. Although in 2021 the Chief Inspector of Environmental Protection issued a negative decision regarding the construction of a lignite open-cast mine from another deposit in Złoczewo, the Bełchatów mine is planning to end mining in the Bełchatów site in 2026 and in the Szczerców site in 2038, keeping extraction at the current level in the following years, i.e., approximately 38–42 million tons a year. According to the adopted schedule, the shutdown of power units will take place from 2030 to 2036.

4.2. Socio-Economic Resilience Index

As indicated above, six variables corresponding to the three adaptive cycle parameters and describing the economic and social domains of resilience were used to build the composite Socio-Economic Index. In economic terms, all analysed regions are characterised by a strong industrial and agricultural profile, in which the energy and mining sectors play a significant role. The calculated values of GDP *per capita* are highest in the poviats where the mines are located, i.e., the Bełchatów powiat (over PLN 10,000), the Koło powiat (PLN 4.7 thousand) and the Zgorzelec powiat (nearly PLN 4 thousand). On average, in the Eastern Wielkopolska Lignite Region and the Łódź Lignite Region, the values of GDP *per capita* are comparable, amounting to PLN 4.1 and 4.4 thousand, respectively. The values of this variable in individual poviats of Eastern Wielkopolska are similar, while in the Łódź Lignite Region they are very diversified, amounting to less than PLN 2 thousand in the peripheral areas of the region. The amount of taxes paid by companies (constituting one of the categories of gminas’ own revenue at the local level) is one of the measures determining the impact of enterprises on the macroeconomic environment. Due to the fact that mines and power plants are among the largest enterprises in the analysed regions, the impact of location is also very visible in the territorial differentiation of the value of the second variable under analysis, i.e., revenue from income taxes *per capita* (RIT). The RIT variable has the largest values in the Bełchatów powiat (over PLN 2 thousand *per capita*), in the Zgorzelec powiat (PLN 1.5 thousand *per capita*) and in the Pajęczno powiat (PLN 1.4 thousand *per capita*), where a few years ago the second open-cast site of the Bełchatów mine was launched. In the Eastern Wielkopolska Lignite Region, tax revenues to gminas’ budgets are much lower due to the fact that mines in that region have been gradually closed for several years.

The disproportions between the poviats in which mines still operate and the rest of the area are not as large as in the Łódź region, and the highest value of the RIT variable is in the town of Konin, with slightly over PLN 1 thousand *per capita*. The last analysed element describing the economy of the lignite regions is the labour market, with the unemployment rate playing a significant role in the context of shutting down mines. The average level of unemployment (the RUR variable) is 6.8% in Eastern Wielkopolska, 6.4% in the Łódź Lignite Region and 6% in the Zgorzelec poviat. These values are comparable to the value for Poland (6.3%), although it shall be highlighted that the Eastern Wielkopolska Region has a much higher value than the entire Wielkopolskie voivodeship, where the unemployment rate is 3.7%. In the Łódź Lignite Region, the highest values of this variable are characteristic of the peripheral poviats of the region, i.e., the Pajęczano poviat and the Łask poviat (8%), while in Eastern Wielkopolska the unemployment rate at the level of 9.7% is recorded in the Konin poviat.

While analysing the social domain of resilience, the authors first examined the level of selected social problems in the regions, which can be indirectly determined on the basis of the number of beneficiaries of social assistance per 10,000 population (the BSA variable). This variable has the lowest value in the Zgorzelec poviat, with about 300 people, while the average in the poviats of the Łódź Lignite Region and the Eastern Wielkopolska Region amounts to nearly 440 people and over 500 people, respectively. The lignite regions also face demographic problems. The median age of the population (the MAP variable), which is on average over 40 years of age (43.5 in the Zgorzelec poviat, 42.1 in the poviats of the Łódź Lignite Region and 41.6 in the Eastern Wielkopolska Region), indicates unfavourable demographic trends, which, in connection with the migration outflow, may lead to depopulation of these areas. In almost all poviats of the lignite regions, the value of the NMP variable defining the number of people migrating to and from a poviat for permanent residence per 10,000 population is negative, which indicates an outflow of the inhabitants. Within the regions, we may observe population movements resulting from suburbanisation; the greatest outflow of population takes place in towns (e.g., Konin and Piotrków Trybunalski), with a simultaneous inflow of inhabitants (positive migration balance) in the surrounding poviats. In summary, it may be noticed that the values of the analysed indicators referring to the social dimension are not related to the location of mines, as is the case with the economic indicators.

In general, the composite SERes Index has assumed similar, medium-high values in the three lignite regions under analysis, ranging from 1.62 to 1.83, which indicates that these regions are similar to each other (Table 4). However, an analysis of the sub-indices reveals significant differences both among and within the regions, which may affect the just transition process (Figure 4). The adaptive cycle analysis carried out above has indicated that the Zgorzelec Lignite Region is currently in the release phase, which is confirmed by low values of the potential and resilience indicators and a very high value of the Connectedness Sub-Index (CSI). In the Eastern Wielkopolska Lignite Region, which is currently undergoing its reorganisation phase, the values of individual sub-indices are exactly opposite to the Zgorzelec Lignite Region—the region's potential and resilience are high, and the connectedness is low. The study of the development of the Łódź Lignite Region in the context of the adaptive cycle has shown that the region is still in the conservation phase, which is characterised by high potential and connectedness parameters as well as decreasing resilience. However, the estimated high Resilience Sub-Index (RSI) value indicates that the region faces a threat of the rigidity trap, and therefore, it is in one of the pathological states of the system.

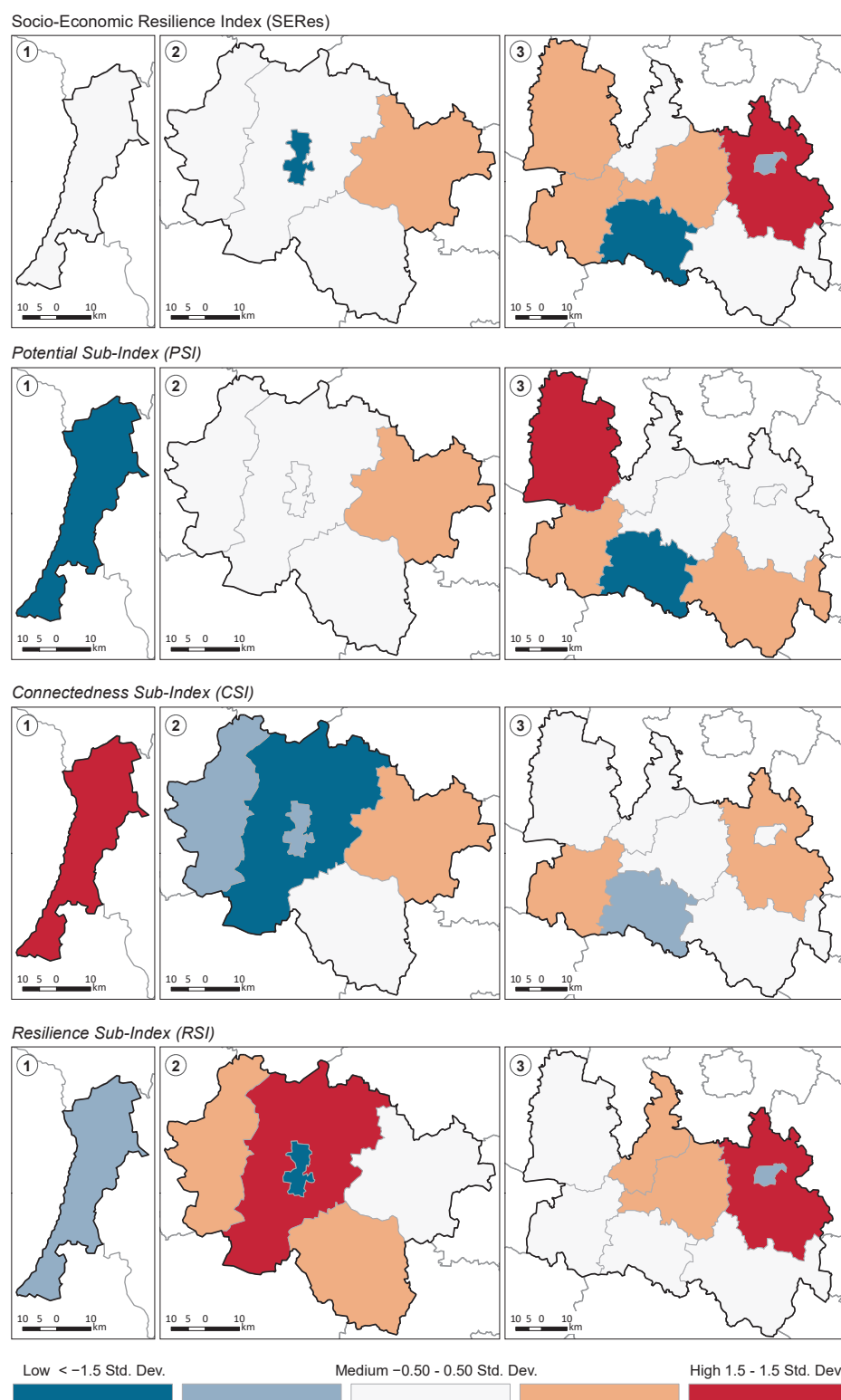


Figure 4. The Composite Socio-Economic Resilience Index (SERes) and sub-indices: PSI, CSI and RSI in the coal regions (1—the Zgorzelec region, 2—the Eastern Wielkopolska region, 3—the Łódź region).

Table 4. Composite socio-economic resilience index (SERes) and sub-indices: PSI, CSI, and RSI in coal regions.

Territorial Unit	PSI	CSI	RSI	SERes Index
Zgorzelec Lignite Region	0.19	1.00	0.43	1.62
Eastern Wielkopolska Lignite Region	0.68	0.33	0.62	1.63
Łódź Lignite Region	0.62	0.58	0.63	1.83

With regard to the Eastern Wielkopolska and Łódź regions, intra-regional differences in the values of the calculated indicators may be observed (Figure 4). The highest and, at the same time, the lowest PSI values are observed in the Łódź Lignite Region. In the Sieradz powiat, the high value of the potential results from a relatively high GDP, but at the same time, from a relatively low share of operating fees and other levies collected from mines in the revenues of local government budgets. In a situation when the mines are closed, the level of revenues of local government units will not change as much as in the gminas of the poviats in which the mines are located. Therefore, despite showing a very high GDP, the potential of the Bełchatów and Zgorzelec poviats is low.

The components of the Connectedness Sub-Index (CSI) values indicate that the labour markets in the poviats where mines are located are diversified in terms of their preparation for the closure of mines. The unemployment rate was very low in the poviats of Turek (4.6%) and Bełchatów (5.5%), while in the poviats of Pajęczno and Konin, it was 8.0% and 9.7%, respectively. A similar differentiation occurs with regard to the scale of social problems resulting from unemployment, poverty or homelessness. The smallest number of beneficiaries (per 10,000 inhabitants) take advantage of social assistance in the Zgorzelec powiat, while the worst situation is in the Turek powiat.

The adaptive capacity of poviats expressed by the Resilience Sub-Index (RSI) shows the lowest intra-regional variation. The most favourable values of the median age of the inhabitants and the migration balance are characteristic for the poviats where the mines are located (the poviats of Konin and Turek in the Eastern Wielkopolska Lignite Region and the powiat of Bełchatów in the Łódź Lignite Region), as well as the poviats surrounding regional centres, i.e., the city of Konin and the city of Piotrków Trybunalski. However, these values are unfavourable in the cities themselves.

5. Discussion and Conclusions

The current economic condition of many countries and regions depends largely on the ability to meet their energy needs [67,68], and energy resilience has been one of the key elements of state security in all areas—political, economic and social [69,70]. Thus, the scientific interest in this subject is very large, including various problematic and methodological contexts. Recently, apart from the issue of energy transformation connected with the requirements related to the EU policy (the Green Deal), there have also been other conditions determined by the (post)pandemic situation [13,71]. Research in this area is therefore necessary, as it can support decision-making processes also in the regions which are economically dependent on the extraction and processing of energy resources, and thus subject to the energy transformation policy [72–74].

The results of the research presented in this article show the condition of the three Polish lignite regions at the beginning of the coal transition process. The use of the adaptive cycle and resilience framework has made it possible to conclude that these regions are currently in three different phases of the adaptive cycle regarding the challenge of the planned closure of mines. Although all analysed regions assume their local economies to become independent of the mining industry and plan to modernise and increase their attractiveness, the adopted time horizons are different. Among the Polish lignite regions, the most advanced in the transformation process is the Eastern Wielkopolska Region, in which the transition from coal in the power and heating sectors is planned to take place fastest, i.e., by the end of 2030. The parameters of the adaptive cycle model also indicate

that this region has already entered the reorganisation phase. The large-scale nature of the open-cast mines in Wielkopolska and their gradual closure in recent years have allowed the region to gain some experience and work out a TJTP [75], in which the development goals set are ambitious, but at the same time achievable. On the other hand, in the Zgorzelec Region, which is also the oldest lignite mining region in Poland, the closure of the Turoszów mine is not planned until 2044. Although the analysis of the adaptive cycle shows that the region has already entered the release phase, the economic structure of the Zgorzelec powiat is strongly dependent on the mining and energy sectors. Hence, it may be assumed that this small region will be affected most by the transformation. The transition to a climate-neutral economy will mean decommissioning and ultimately closing plants that have been the economic pillar of this area for several decades [76].

In the last analysed region—the Łódź region—the period of withdrawing from coal is longer than in Eastern Wielkopolska, but the closure of mines is expected earlier than in Turoszów. According to declarations in the TPJT [77], shutting down the power units in the Bełchatów Power Plant will take place from 2030 to 2036, while the current exploitation of lignite deposits in the Bełchatów and Szczerców sites will be terminated in 2026 and 2038, respectively. The results of the conducted analysis have indicated that the region is still in the conservation phase. Due to the very rich coal resources, the Bełchatów mine obtained concessions for mining in two deposits (Bełchatów and Szczerców) for the next several years. Additionally, the previously unexploited lignite deposits in Złoczew have been considered in the Polish Energy Policy until 2040 [3] as prospective resources due to their strategic nature—their security is provided, and their operation will depend on the investors' decisions. Therefore, the economy of the region remains predominated by the energy and mining sector, which results from geological and historical premises. The analysis of the adaptive cycle parameters has revealed that the Łódź Region faces a threat of the rigidity trap. The strong impact of the mine on the region and its functioning based on the resources generated by the energy and mining sector make it difficult to identify an alternative development path and to adapt to the projected changes.

The contemporary discussion on the energy transformation is also a question of the transformation of territorial systems, interference in the functioning of regional settlement systems, in which various elements (subsystems) related to a superior function (mining and energy production) can be distinguished. Changes in this key subsystem will affect the functioning of all other activities, not only in the area of transformation, but also in the region and the country. Furthermore, the area of transformation itself is not homogeneous in this respect, and the immediate sphere of economic and social influence of mines and power plants encompasses various types of rural and urban functional units. Thus, the sensitivity of territorial systems to transformational changes may be very different, which was already observed during the economic transformation in Poland in the 1990s [78,79]. The energy transformation requires a lot of attention not only in terms of economic and social changes, but also an individual approach to various areas it will affect. The use of the model of adaptive cycles for analysis makes it possible to apply it in future research in relation to other coal regions, including hard coal, both in Poland and other countries, which in turn will allow for comparative studies. Moreover, the obtained results may constitute an important element in the formulation of policy implications, and the resulting recommendations may be taken into account when reformulating or revising the strategy for the lignite industry in Poland.

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