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The Impact of Opencast Lignite Mining on Rural Development: A Literature Review and Selected Case Studies Using Desk Research, Panel Data and GIS-Based Analysis

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Abstract: The future of opencast mining and energy production based on conventional resources is one of the most important issues being discussed in international forums. The whole discussion is becoming increasingly heated and takes on a special significance with the drastic increase in energy commodity prices that has occurred with the outbreak of war in Ukraine. Especially in a country like Poland, these issues are accompanied by heated discussions between miners, the government and citizens. It should be emphasised that Polish lignite mining currently produces about 35% of the cheapest electricity in Poland and also creates many jobs. The aim of this study is to assess the possibility of continuing opencast mining and its impact on rural development—both from an environmental and socio-economic point of view. The study was conducted for two municipalities in Poland where opencast lignite mining plays an important role, namely Kleszczów and Kleczew. As a result, it was found that in the case of the studied municipalities, the presence of opencast mining has contributed to their development, and the application of modern environmental protection technologies and recultivation have reduced the difficulties associated with mining. On the other hand, the decision to start mining should be the result of a comparison between the potential environmental and social benefits and damages. In some cases, mining is beneficial for community development and leads to new opportunities for agriculture and tourism after reclamation. The study is a combination of different methods, i.e., case studies, GIS remote sensing analysis (based on Landsat data) and econometric analysis for selected socio-economic data.

Keywords: lignite life cycle; reclamation; opencast mining; sustainable development; rural development; geographic information system (GIS); remote sensing; panel data analysis; Granger causality; Normalised Difference Vegetation Index (NDVI)

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1. Introduction

The ongoing transformation of the energy sector in Poland [1] and worldwide has a significant impact on the economic development of individual countries and leads to a number of social problems [2,3]. As is well known, the use of renewable energy sources and low-carbon technologies to produce clean energy has become a common aspiration [2,3]. The starting point for such energy policies is the assumption that it is possible to profoundly reduce greenhouse gas emissions while maintaining economic growth and even increasing economic activity and prosperity [1,4]. However, it is often overlooked that traditional energy sectors such as lignite mining have created a large number of jobs and that the cessation of fossil fuel extraction will have a negative impact on employment and thus on the overall economy of mining regions [1,5]. The analysis conducted by Wójcik-Jurkiewicz et al. [1] clearly shows that about half of all Polish mining employees who left the mining sector did not find employment in other industries and remained unemployed. As one of the important reasons for this state of affairs, Wójcik-Jurkiewicz et al. [1] cite the educational level of miners, which is significantly below the average of the labour market. This problem mainly affects regions where hard coal and lignite are mined. Many lignite mines are under increasing pressure due to initiatives to reduce CO_2 emissions [6], the rapidly growing renewable energy capacity and the promotion of other alternative technologies [7]. According to a 2018 EU study, Poland is the only country in the EU where coal and lignite mining accounts for more than 50% of total electricity generation [8,9]. However, although Poland's lignite reserves are huge (over 23.5 billion tonnes) and the mining sector itself has significant potential, the future of Polish lignite mining does not look optimistic from a socio-economic perspective. This situation is of course related to the European Union's climate and energy policies, as well as social and environmental problems [9].

The future of the mining industry in Poland is the subject of constant negotiations between the government and the miners, who represent an important professional group in the country. Over the years, there have been various ideas from those in power to regulate this particular industry. One of the most recent such initiatives was the drafting of the so-called Coal SpecLaw in April 2019, which sought to introduce certain facilitations in obtaining concessions for the mining of lignite from deposits important to the national economy, i.e., those with an average thickness of more than seven metres [10]. After numerous protests by environmentalists and the media [11], and in connection with the end of the legislative period of the Polish Parliament, the project was withdrawn in the phase of legislative preparations.

It is also worth noting that in September 2020, the Polish government signed a memorandum on the transformation of the mining industry [12]. According to this document, underground coal mining in Poland will only be allowed until 2049. This means that after this date, the mining of this most important energy resource for Poland will be completely stopped. One of the effects of such a declaration could be a renewed renaissance of lignite mining, which will gain importance as a strategic raw material for achieving energy self-sufficiency. In this context, it should be clearly emphasised that no other alternatives are currently in sight. Finally, the prospects for the construction of a nuclear power plant in Poland remain uncertain [13], and natural gas supplies from the USA and Russia are not a source that offers sufficient reliability and continuity to maintain the stability of the Polish energy system. This has probably never been more evident than after 24 February 2022—with the outbreak of war in Ukraine, which led to the Polish government imposing a full embargo on Russian coal imports as early as mid-April 2022.

The geopolitical situation in the world and the need to reduce CO_2 emissions [14] require a more conscious approach to the exploration of energy resources [15] and the search for more environmentally friendly methods of mining and processing lignite. The aim of this study is to assess the possibility of continuing lignite opencast mining and its impact on rural development—both from an environmental and socio-economic point of view. More specifically, one of the research tasks is to analyse the balance of gains and losses in order to better understand whether opencast mining tends to have positive (e.g., social and economic) or negative (e.g., environmental) impacts in rural areas.

The article is structured as follows. In Section 2 we go into the methods and materials we use in this article. Section 3 reviews the literature related to the topic of the study. In Section 4 we describe the characteristics of the spatial areas (two different municipalities) that are the subject of the analysis carried out in this article. Section 5 is devoted to desk analysis (The Desk or Desk Research analysis consists of the research, evaluation and possible re-processing of information already collected from official sources.) and panel data analysis of two selected Polish municipalities where lignite is mined. In Section 6, we provide a discussion, and Section 7 presents conclusions from the conducted research.

2. Materials and Methods

As already mentioned in the introduction, one of the research tasks in this article is to take a closer look at the profit and loss balance of selected lignite mining municipalities. In this way, it will be possible to better understand whether lignite opencast mining in rural areas brings positive or negative impacts. The article assesses both socio-economic and environmental factors. Among the relevant indicators to be considered in assessing the effectiveness of continued lignite mining, the following should be considered: (1) social indicators (and costs)—the number of people displaced by resource extraction, the number of villages closed, the number of inhabitants in the municipality and their changes (out-migration, population growth); (2) economic indicators—municipal budget revenues, municipal investment expenditure, number of investments made in the municipality, degree to which the municipality is equipped with technical infrastructure, number of jobs in the municipality; (3) environmental indicators—degree of air pollution by particulate matter, sulphur oxides and nitrogen oxides related to lignite mining, extent of depression cone, degree of pollution of the soil surface; (4) spatial indicators—land use structure before, during and after mining of the raw material, the qualitative structure of the soil in the municipality.

More specifically, the study is based on the analysis of desk research (i.e., the analysis of data coming from the Central Statistical Office (CSO) and municipalities) and geographic information systems (GIS) that allow the integration and collective analysis of geospatial data from different sources, including satellite imagery (e.g., LandSat 9), GPS datasets and text attributes associated with a given space. In other words, GIS is a system that creates, manages, analyses and connects data to a map and integrates location data (in the case of this article, data about lignite opencast mines in two different municipalities in different voivodeships) with all kinds of descriptive information. As part of the GIS data types, the images we use are a powerful visual aid and serve as a source for derived information such as planimetry and classification schemes to derive information such as land use/land cover.

The study provides a detailed analysis and comparison of the overall situation in two different municipalities, i.e., Kleszczów (Łódź Voivodeship) and Kleczew (Wielkopolska Voivodeship), with special attention to the period before the start of lignite mining, after the start of mining, and the current state. More specifically, a review of the area designated for mining is carried out and the number of villages and people displaced by mining is determined. On this basis, trends in the characteristics of the two communities were examined, both in terms of continued land use for non-agricultural purposes and in terms of in-migration and out-migration of residents. Initially, population out-migration and a deterioration of the financial situation of the municipalities were expected. After a few years, there should be a gradual influx of new residents seeking work in the mines or in other businesses that are being established in the newly created settlements.

Historical satellite images and more recent orthophotos showing changes in land cover, as well as statistical data from the Central Statistical Office, were used for the analysis. The development strategies of the two municipalities and the environmental impact assessments prepared for the investments were also analysed. The next step of the study was to compile data on income and expenditure from the municipal budgets for each year of a mine operation, and then to assess and compare the gains with the losses associated with land degradation and the prevention of the use of land designated for mining and adjacent land for agricultural or forestry purposes (due to the negative impact of the subsidence cone) [16]. The final phase of the research was to develop a vision for the future of these communities, and the planned methods of reclamation and use of the mine site after closure.

3. Literature Review

Lignite is one of the cheapest energy sources for electricity generation [17–21]. More specifically, the cost of generating electricity from lignite is about 30% less than that of hard coal [22], so it seems sensible to manage its resources optimally. There are 17 large lignite mines in the European Union [8]. Germany (five mines) and Poland (three large mines) dominate both in terms of the number of mines and production volume. Poland ranks fifth in the world in terms of the amount of lignite resources mined [9]. The largest lignite producer in Poland is KWB Bełchatów with an annual production of about 42.1 megatonnes [23]. In terms of output, it is second only to the mines in the German region of Cologne, which produce about 60 megatonnes of lignite per year. Figure 1 shows the locations of active lignite and hard coal mines in the EU and their annual production by NUTS-2 regions. It shows that Poland and Germany have a dominant share in coal production. Apart from Germany and Poland, other lignite mining areas in the EU are located in Romania, Bulgaria, Greece, Hungary and Slovakia. It is also worth noting that in most countries, opencast lignite mining is rarely carried out in parallel with underground hard coal mining [24]. Poland is the only country in the European Union where such a combination of activities takes place [22]. In the other EU countries, one of the two types of coal usually dominates.

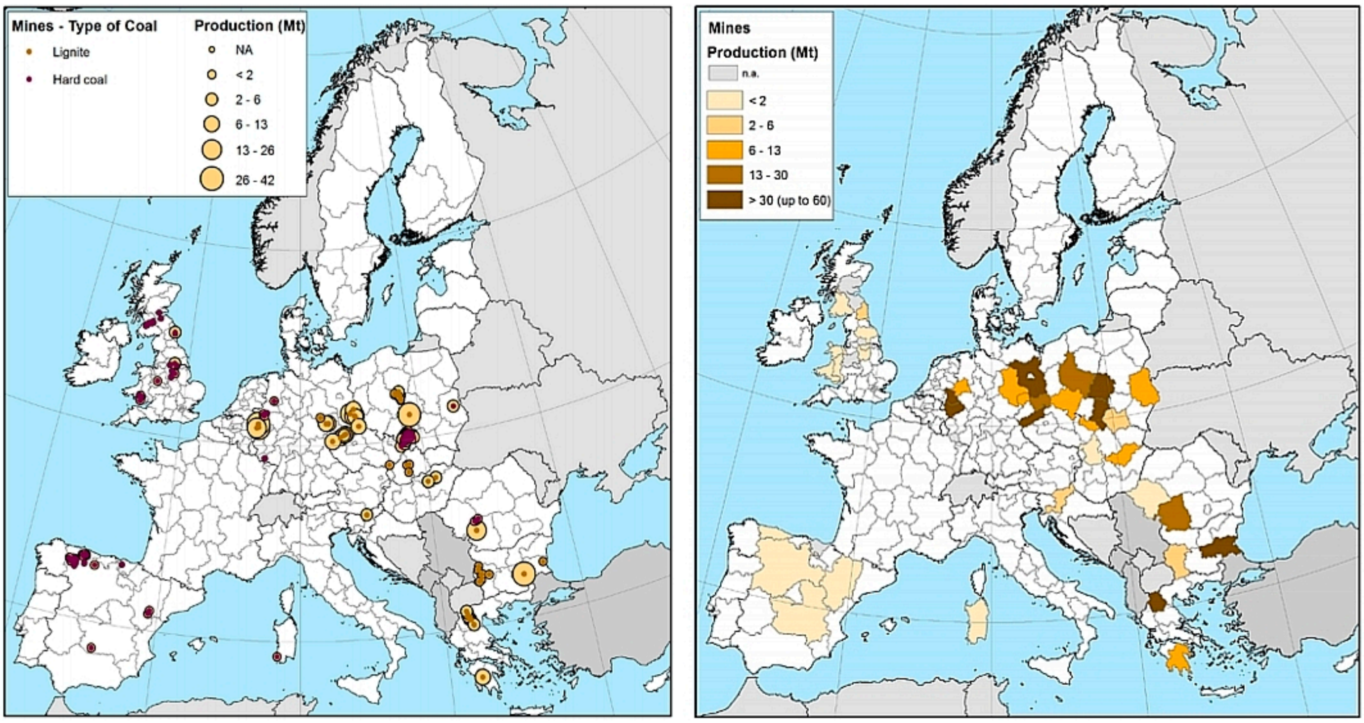

Figure 1. Locations of active lignite and hard coal mines in the European Union (**left**), and the annual production of coal mines in NUTS-2 regions in the European Union (**right**) [Source: EU coal regions: opportunities and challenges ahead].

As for the NUTS-2 regions (i.e., units corresponding to e.g., Polish voivodeships or German Laender in EU terminology) where lignite is mined, annual production varies from less than 2 megatonnes in smaller mining regions up to 60 megatonnes, as can be seen in Figure 1. Again, it shows that the dominant regions are in Poland and Germany. Importantly, the start of opencast lignite mining in a given region is associated with the creation of many new jobs [22,25,26], both those directly related to lignite mining and those indirectly related, such as processing [22]. This is particularly evident in large lignite deposits with extensive extraction. For example, in the Łódź region, where KWB Bełchatów (and its opencast mines "Bełchatów" and "Szczerców") is located, about 8900 people work in mining. If we add the employees of the subsidiaries that support the mining process and the employees of the power plant adjacent to the mine, the number of jobs increases to 12,500 [27], and with the development of further opencast mines, this number could even increase. The mine is thus the most important workplace for the people in this region. Compared to other mining regions in Europe, the Łódź region is one of the largest in the European Union [8]. As can be seen in Table 1, similar numbers of jobs are also created in the main lignite mining regions in Romania, Bulgaria and Germany. At this point, reference should be made to the study by Kasztelewicz et al. [22], who point to a number of factors why lignite is so strategically important for Poland, and especially for regions such as Łódź and Bełchatów. The advantages of this fossil fuel resource include relatively large and recognised reserves (In 2020, lignite reserves in Poland were estimated at around 5572 million tonnes, according to Statista), years of experience in the field, thanks to which Poland has very qualified technical, engineering and managerial staff, very good scientific and technical support in the form of research institutes and centres that work closely with the mining industry, excellent technical support aimed at the mining industry, and extensive cutting-edge technologies and machinery that are known worldwide.

Table 1. The number of jobs created by coal mines and their subsidiaries.

NUTS-2	Region	Coal Related Jobs
PL22 (Poland)	Śląskie	82,500
RO41 (Romania)	Sud-Vest Oltenia	13,100
BG34 (Bulgaria)	Yugoiztochen	12,700
CZ08 (Czech Republic)	Moravskoslezsko	10,600
DEA3 (Germany)	Munster	10,000
CZ04 (Czech Republic)	Severozapad	9700
PL11 (Poland)	Łódzkie	8900
PL31 (Poland)	Lubelskie	5800
DEA2 (Germany)	Koln	5700

Source: EU coal regions: opportunities and challenges ahead.

One of the problems often cited as an argument against lignite mining is the emission of large amounts of air pollutants during combustion, which are harmful to the environment, health and microclimate [8,28–31]. It is worth mentioning that the combustion of lignite naturally contributes to the emission of harmful pollutants, i.e., inhalable particles, with diameters that are generally 10 µm and smaller (PM_{10}), sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) [30], as well as various dusts and heavy metals such as cadmium, lead, mercury [31], in addition to carbon dioxide emissions. Depending on the source of origin, lignite can contain various toxic heavy metals [31], and even radioactive substances that occur as by-products of combustion in the fly ashes. This further increases the health risks [32]. Above all, it should be emphasised that lignite has the peculiarity that its combustion releases more carbon dioxide and sulphur compared to other types of coal while producing the same unit of heat (in other words, it is less energy-rich) [33]. For this reason, lignite is considered by environmentalists to be the most harmful to human health [34], although it should be noted here that scientists are working on technologies to reduce the negative effects of burning this fossil fuel [30,32]. The study by Nanaki et al. [29] suggests that in order to significantly reduce GHG emissions, the technologies used would need to be replaced with more advanced ones that could help improve emissions (i.e., NO_x, SO_2, and PM_{10} emissions) over the life cycle of lignite. However, looking at the problem more broadly, it is not the gas emissions that pose the greatest threat from a lignite life cycle perspective, but the category of respiratory impacts and associated diseases [29]. To assess the harm from a health impact perspective, it is worth citing the study by Markandya and Wilkinson [35], who compared the health burden of electricity generation from different sources, including hard coal and lignite. The study found that for lignite, the softest and most polluting form of coal, each TWh of electricity generated causes 32.6 deaths, 298 serious illnesses and 17,676 minor illnesses. For hard coal, the statistics are slightly more favourable, i.e., for every TWh of electricity generated from this resource, there are 24.5 deaths, 225 serious illnesses, including hospitalisations, congestive heart failure and chronic bronchitis, and 13,288 minor illnesses.

The map below (in Figure 2), and the following lists (Tables 2 and 3) show and compare the most important lignite deposits in Germany and Poland. From the analysis of the data and materials presented, it appears that in the case of Germany, complete data on the number of inhabitants and localities displaced are available, which cannot be said for Poland, for which most similar data are missing (taking into account all reports at both national and EU levels). Significantly, such data is also missing from local archives, as evidenced by information from mine workers and officials [27,36].

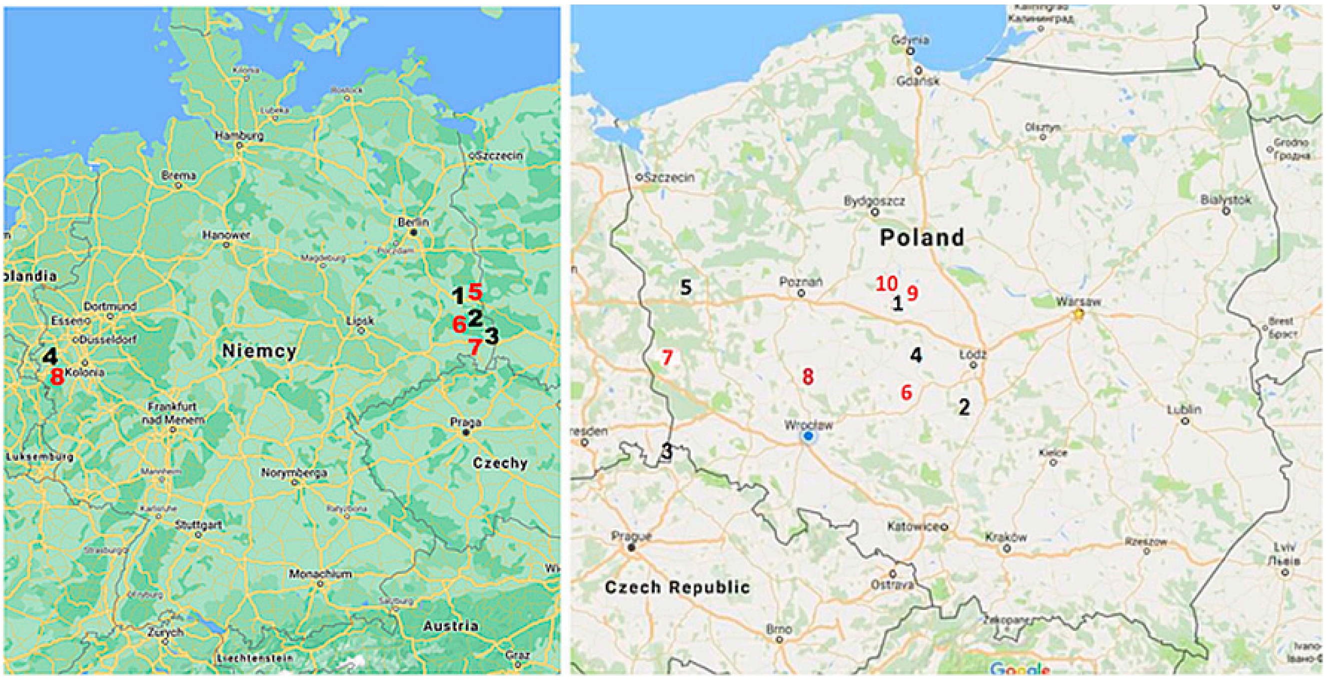

Figure 2. Location of exploited and prospective lignite deposits in Germany and Poland (Source: own elaboration).

Table 2. Basic data on lignite deposits in Germany.

Mine No.	Name of the Mine	Size of the Mine	Number of Displaced Households	Status
1	Janschwalde	6015 ha	5 villages	EXISTING MINE
2	Welzow Sud I	11.2 ha	17 villages	
3	Nochten I	No data	No data	
4	Garzweiler I	7200 ha	44,064 persons G. I + II	
5	Janschwalde Nord	3100 ha	900 persons	PLANNED MINE
6	Welzow Sud II	1900 ha	810 persons	
7	Nochten II	1200 ha	1700 persons	
8	Garzweiler II	3800 ha	As above	
IN TOTAL	-	23,226.2 ha	22 villages + 47,474 persons	

Source: own elaboration based on Ecological Association EKO-UNIA report. (http://eko-unia.org.pl/raport/report_international.pdf, accessed on 8 June 2022).

The scale of resettlement in Germany is much larger, but it should also be taken into account that the scale of ongoing lignite mining in Germany is much larger than in Poland and that the country has also introduced a corresponding law regulating these issues of resettlement related to lignite mining. In connection with Tables 2 and 3, it should be noted that Germany has been struggling for years with a number of difficulties related to forced resettlement in the area of opencast lignite mines. This problem was clearly regulated in the German Mining Act; however, from a social point of view, this law—years later—is perceived very negatively [37]. In this context, the situation in the GRD is the worst. Former inhabitants of mining communities were often forcibly resettled under much worse conditions than in other regions of the country. The situation was much better in North

Rhine-Westphalia, for example, where residents (resettlers) were adequately compensated for the costs of relocation to other places. In Poland, on the other hand, at least several new opencast mines are planned [37], but the plans are notoriously torpedoed in connection with EU climate policy. According to Kubiczek [37], it is very difficult to get exact figures on the number of people displaced by Polish opencast mines. A rough estimate of the number due to the development of new opencast mines is around 26,800.

Table 3. Basic data on lignite deposits in Poland.

Mine No.	Name of the Mine	Size of the Mine	Number of Displaced Households	Status
1	Konin	12,379 ha	Just partial data (233–Jóźwin II B, 500–Tomisławice)	EXISTING MINE
2	Bełchatów	9818 ha	No data	
3	Turów	6600 ha	No data	
4	Adamów	5678 ha	No data	
5	Sieniawa	55,381 ha	0	
6	Złoczew (Bełchatów)	32,960.6 ha	3041	PLANNED MINE
7	Gubin-Brody	10,363 ha	2367	
8	Poniec-Krobia-Oczkowice	10,000 ha	6000–11,000	
9	Dęby Szlacheckie (Konin)	2500 ha	2500	
10	Ościsłowo (Konin)	1580 ha	1901	
IN TOTAL	-	91,933.981 ha	16,542–21,542	

Source: own elaboration based on Ecological Association EKO-UNIA report. (http://eko-unia.org.pl/raport/report_international.pdf, accessed on 8 June 2022).

In many countries, there is currently a broad discussion about the future of mining and the utilisation of lignite deposits [9,22,26,32,38,39]. The deposits exploited so far and those where mining started 30–50 years ago are approaching exhaustion. An important element of our analysis is the presentation of both the negative and positive impacts of opencast lignite mining. Table 4 summarises the negative impacts over the life cycle of lignite, mainly in terms of the environment, but also in a socio-economic context. As can be seen in this table, the negative impacts are primarily focused on environmental issues [7,40,41].

On the other hand, besides the negative effects, opencast mining also brings a number of positive effects. As can be seen in Table 5, most of them are mainly related to the socio-economic situation of the local communities, which are in some way connected to the life cycle of lignite.

Table 4. Negative impacts in lignite life cycle.

Problem	Description/Details
Storage and securing of mining waste	Waste and overburden are stored in internal dumps on the mine site or in external dumps that form ground elevations. Without proper management and reclamation, mining waste dumps can generate hazardous levels of dust, contaminate groundwater or simply blight the local landscape [41,42]. Of course, it must also be pointed out that there are preconditions for mitigating these negative impacts based on innovative technologies for the integrated management of coal deposits and mining waste, as shown in the work of Griazev et al. [43], where these authors demonstrated this using the example of the Moscow Coal Basin.
Mining-induced displacement and resettlement	The establishment of an open pit mine requires the protection of the mining area with a buffer zone, and in the case of Polish open pits, it is assumed that the area within 400 m of the location of the machinery cannot be developed and must be cleared. Such a measure usually means resettling the inhabitants of several villages and providing a new place to live [44,45].
Traffic/Communication problems	The establishment of an open pit mine is often associated with the decommissioning and closure of some existing roads, resulting in the disruption of transport routes that previously served the communal area; this may be the result of groundwater drainage and cone subsidence [46]. Therefore, new roads usually need to be built to ensure the free flow of traffic between different villages and through the municipality [47].

Table 4. *Cont.*

Problem	Description/Details
Significant changes to the landscape of the community/terrain relief	Lignite mining itself is accompanied by significant alteration of the existing landscape and terrain relief [41,42], with flat lowland areas changing their character through the installation of opencast mining, the extraction of deposits and the creation of stockpiles for the mined coal and external spoil heaps. In this context, reference should be made to the study by Henselowsky et al. [48], who quantitatively assessed the mining-induced changes in the terrain relief in one of the oldest and currently largest lignite mining areas in Europe, the Rhenish lignite mining area in Germany. The results of their study show that almost half of the study area (184 km^2) is characterised by some relief deficit and about 15% has positive relief differences. Also, Raab et al. [49] have described how lignite mining destroys entire landscapes, using the example of lignite mines in Niederlausitz (Brandenburg, Germany).
Disturbance of already existing social ties/Mining Induced Displacement and Resettlement (MIDR)	The impact of the loss of social ties is usually felt shortly after the works begin, as the need to relocate and disperse villages means that many residents have to move to another community to find work or a friendlier place to live. This in turn destroys the long-standing neighbourly relationships between villagers that are broken up in the context of mine development [45,50]. Especially in the initial phase, most of the new residents are also mine workers, which has a negative impact on the social diversity that originally existed in the area. In this context, reference should be made to the study by Terminski [45], who highlights the importance of the loss or significant restriction of access to basic material and immaterial resources, mentioning, among other things, the loss of access to land, pasture, forests and clean water, as well as the loss of socio-economic ties.
The effects of the subsidence cone/Damage caused by mining	Coal mining requires drainage of the surface mining area to reduce the potential for water intrusion. However, this leads to the hydrological destruction of a much larger area around the open pit mine. The lowering of the water table leads to reduced productivity of soils fed by groundwater, while it has little effect on soils fed by stormwater retention [16,42,46]. Citing the study by Motyka et al. [46] for lignite mining in the Bełchatów mine, it can be stated that the environmental changes caused by lignite mining are generally very significant. The fact is that lignite mining requires intensive, deep drainage of groundwater, which leads to the formation of a large cone of depression. At the time the authors conducted their study (i.e., in 2007), the area affected by the changed hydrodynamic conditions covered about 450 km^2, and the local lowering of the groundwater level even reached more than 250 m in some places.
Deforestation	The construction of a new open pit mine requires not only the relocation of local communities but also the clearing of forests in the area of the proposed mine, which will decimate vegetation in the community and increase vulnerability to air pollution caused by the mine and power plant.
Air pollution	Emissions of dust and other hazardous compounds and metals pose a serious threat to the health of local residents. Emissions of dust, sulphur dioxide (SO_2), carbon dioxide (CO_2), nitrogen oxides (NO_x) or mercury caused by the activities of mines and power plants are particularly dangerous [51].
Overdominance of mining and energy for the local economy	It must also be emphasised that in the early stages of mining, the local economy focuses on mining and crowds out other activities, but over time this trend often reverses and the number of manufacturing and service enterprises in other sectors begins to grow.

Source: own elaboration.

The reasonableness of the above arguments can be confirmed by analysing the list of the richest municipalities in Poland (Table 6, based on the data of the Central Statistical Office for 2019). Among the 2477 municipalities, the municipality of Kleszczów (which we discuss in more detail in Section 5.1) takes the first place. The largest lignite mine in Poland and one of the largest in the world, KWB Bełchatów, operates in this municipality. In turn, the municipality of Rząśnia, which ranks fifth, is home to the "Szczerców" mine. A high 113th place is occupied by the commune of Kleczew (to which we devote more space in Section 5.2), where the mines of KWB Konin are located. For comparison, it should be noted that the other highly ranked municipalities are usually important tourist destinations such as Świeradów-Zdrój, Rewa, Krynica Morska, Karpacz or municipalities with large industrial or service centres.

Table 5. Positive impacts in lignite life cycle.

Problem	Description/Details
Increased revenue for the municipal budget	The levies collected for the benefit of the local self-government units mainly include 60% of the mining tax, the land tax, the tax on means of transport and part of the corporate income tax and the personal income tax. In addition, the provincial budget is supplemented by annual levies and fees for taking land out of agricultural or forestry production [52,53].
More development opportunities for the municipality	It should be noted that the municipality in which a large open-cast mine is located usually changes its character from typically agricultural to mining and energy production oriented. However, this activity also contributes to the creation of other new investments, such as a special economic zone and business incubators, which allow new businesses to locate on preferential terms and offer numerous incentives, including tax breaks [54,55].
Stabilised sources of funding for municipal investments	With a steady income for the community budget in mining-oriented communities, it becomes easier to plan long-term activities. Therefore, many initiatives are being taken in rural regions near mines, thanks to which many innovative technical solutions are being implemented, e.g., local community services (independent external providers), including their own access to water, gas, sewage or electricity and ICT networks [56].
Enrichment of the local labour market through the establishment of subsidiaries of the mine and the power plant	The local labour market benefits from companies in the mining sector. Companies that provide services to the sector have many jobs to offer. They also have very different business profiles, e.g., related to the use of groundwater, the extraction and sale of overburden rock, coal transport or the repair and overhaul of mining machinery and equipment. This creates thousands of jobs for the local population and skilled workers from all over the region [27,36].
Environmentally friendly use of the extracted raw material	Applications with lignite-based products to improve the physicochemical properties of soils, especially sorption properties [57].
By-products of lignite combustion as a potential source of industrially desirable metals	The by-products of lignite combustion can be a potential source of many metals sought after by industry. Indeed, lignite combustion ash contains strategic metals, metalloids and rare earth elements (REEs). The study by Kermer et al. [58] seems to be very valuable as the authors have assessed the possibility of using this potential raw material for industrial purposes. The authors point out that such valuable pyrolytes, which are a source of metals sought after in industry, can be extracted in Germany in the Lausitz region.
Development of local entrepreneurship	Mining activity stimulates the development of local entrepreneurship, which is based on favourable conditions for the establishment of new enterprises already mentioned [56].
Increasing the prosperity of the local population	It is noteworthy that per capita incomes in the municipalities with open-cast lignite mines are generally much higher than in other municipalities and among the highest in the voivodeship. This is confirmed by statistical data [59] as well as by findings we gathered in personal conversations with representatives of the municipal authorities [56].
Creation of a stable consumer market	As mentioned above, mining creates exceptionally favourable economic conditions (due to the greater number of existing businesses in the region), thanks to which consumers have the opportunity to choose between the products and services offered by different producers, sellers or suppliers and to seek the offer that best meets their needs, which increases competitiveness in the local markets and improves the quality of the products and services offered [59].
Reduction of the unemployment rate	Thanks to the large supply of jobs, unemployment in municipalities where mining is practised is usually significantly lower than the average for the region as a whole. In the municipalities of Kleszczów and Kleczew, for example, the unemployment rate in 2019 was 2.1% and 4.2%, respectively, while the Polish average was 5.2%.
Reducing the phenomenon of economic migration of the young generation	Importantly, working in the mining sector, combined with the abundant local services and educational opportunities in the region, means that the younger generation is less likely to have to move to the cities in search of work or school, increasing the region's development opportunities [59].
Strengthening the educational aspirations of indigenous young people	In addition, mining companies and other newly created jobs need skilled labour. Therefore, specialised schools, including vocational and technical schools, as well as specialised secondary schools offering education in mining-related subjects, are often established near the mines [59].

Source: own elaboration.

Table 6. Per capita income in selected municipalities in Poland.

No.	Municipality	Income per Capita (in PLN)	Voivodeship
1.	Kleszczów	43,999	łódzkie
2.	Świeradów-Zdrój	15,898	dolnośląskie
3.	Rewal	14,288	zachodniopomorskie
4.	Krynica Morska	13,582	pomorskie
5.	Rząśnia	13,120	łódzkie
6.	Dziwnów	11,453	zachodniopomorskie
7.	Kobierzyce	10,517	dolnośląskie
8.	Karpacz	10,243	dolnośląskie
9.	Darłowo	10,151	zachodniopomorskie
10.	Jerzmanowa	9874	dolnośląskie
...	...	...	...
113.	Kleczew	6402	wielkopolskie
...	...	...	...
	Poręba	3263	śląskie
	Bolesław	3195	małopolskie
	Zawadzkie	3172	opolskie

Source: own elaboration based on the data of the Central Statistical Office.

In addition to the background information and theoretical context, we have included Table A1 in Appendix A, which in a way summarises the main studies that deal with opencast lignite mining and its socio-economic and environmental significance (focusing on both negative and positive impacts). Our aim is to briefly characterise these works and show their contribution to the understanding of the problems analysed, thus further expanding the literature in this field.

In order to investigate and assess the actual impact of opencast mining on rural development in specific municipalities, two examples were selected for further analysis: the municipality of Kleszczów (in Łódzkie Voivodeship) and the municipality of Kleczew (in Wielkopolskie Voivodeship). Section 5 analyses the occurrence of negative and positive impacts of mining activities in these municipalities and provides an overall assessment to show whether these municipalities have gained or lost from lignite mining.

4. Spatial Area under Study

The study was conducted in two municipalities in Poland where opencast lignite mining plays an important role, namely Kleszczów (Łódzkie Voivodeship) and Kleczew (Wielkopolskie Voivodeship). Kleszczów is a rural commune in Łódź Voivodeship, Bełchatów District (see Figure 3). It covers an area of 125 km^2. In 2018, it had a population of 6181 inhabitants (according to the Central Statistical Office). On its territory, there are currently 28 villages organised into 10 administrative units. The central part of the municipality of Kleszczów is occupied by the Bełchatów opencast lignite mine, one of the two opencast mines currently in operation, marked in grey (as shown in Figure 3).

Kleczew, in turn, is an urban-rural municipality in Wielkopolskie Voivodeship (see Figure 2), in Konińskie County, with an area of 110 km^2. In 2017, it had 9991 inhabitants (Central Statistical Office). On its territory, there are currently 38 villages organised into 19 administrative units.

On the territory of the municipality, there are two open pits of the “Konin” lignite mine (Figure 4), namely “Kazimierz” (field “Kazimierz North”) and “Jóźwin” (fields I, IIA and IIB). Mining of lignite in the first open pit with a total area of 1045 ha began in 1965 and was completed in 2011. The “Józwin” mine has been exploited since 1971 and its operation is expected to end in 2020.

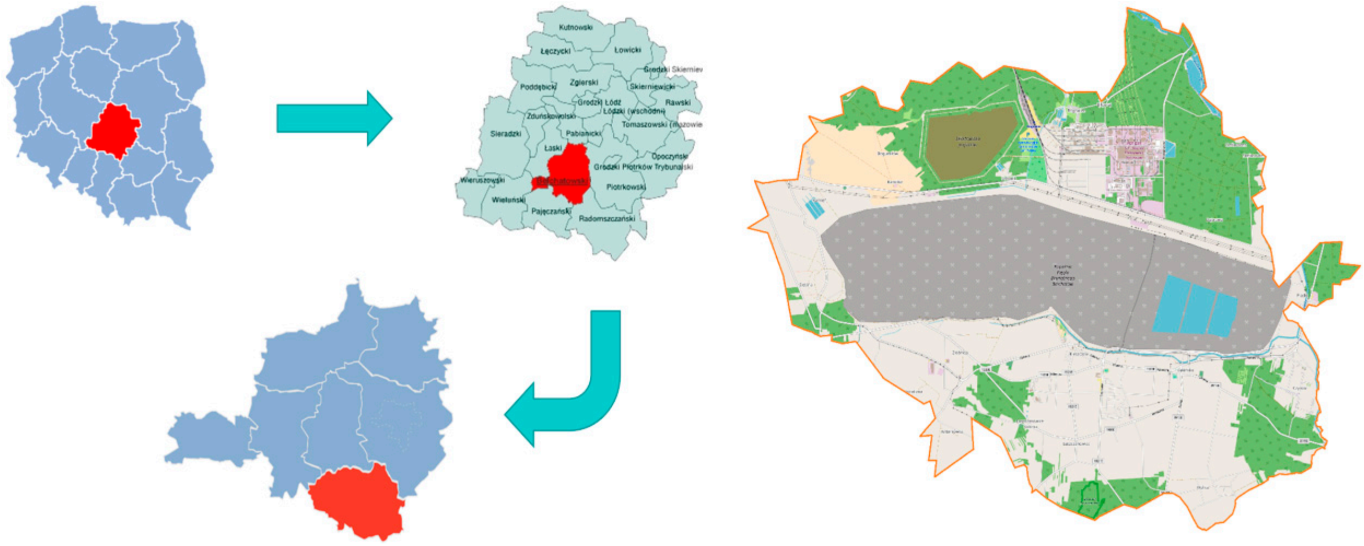

Figure 3. Location of the municipality of Kleszczów in Poland (**left**) and exact location of the open-cast lignite mine in the municipality of Kleszczów (**right**) [Source: own elaboration].

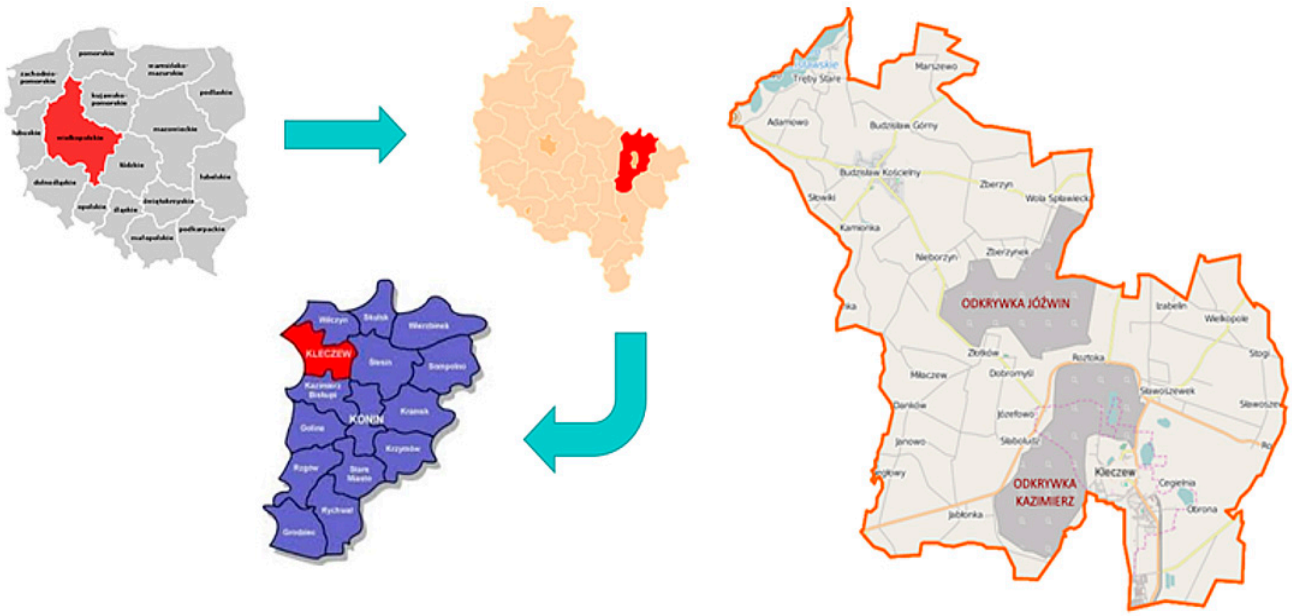

Figure 4. Location of the municipality of Kleczew in Poland (**left**) and exact location of the open-cast lignite mine in the municipality of Kleczew (**right**) [Source: own elaboration].

5. Results

5.1. Case Study 1—Kleszczów Municipality

The beginnings of lignite mining in the municipality of Kleszczów date back to the early 1980s. In the 1990s, extensive resettlements related to mining were carried out in this municipality [60]. It should be noted that Kleszczów was still a typically agricultural municipality in the 1970s before lignite mining began. The approximately 5.3 thousand inhabitants were mainly farmers who extensively cultivated their small, narrow plots of land. There were only six businesses in the municipality in total, employing 81 people. The remaining inhabitants who worked outside agriculture had to commute to work in the nearby towns. In the 1990s, due to the development of mining, several villages were dissolved and the population dropped by about 1500 people to 3736. However, the number of jobs in the businesses located in the municipality multiplied, so that there were 18,671 jobs at that time. This means that the municipality provided almost five times more jobs than its permanent population, which means that it focused on attracting new residents. This trend continued in the following years and the number of inhabitants began to grow again. Housing estates were built in Kleszczów for the employees of the mines and power plants, but also for new commercial and service enterprises. Although the number of administrative units (consisting of an average of two villages) decreased from 17 (in the 1970s) to 10, they developed more intensively, so that already in 2015 the number of inhabitants in the municipality exceeded that before the establishment of the mine and this number continues to increase (see Figure 5).

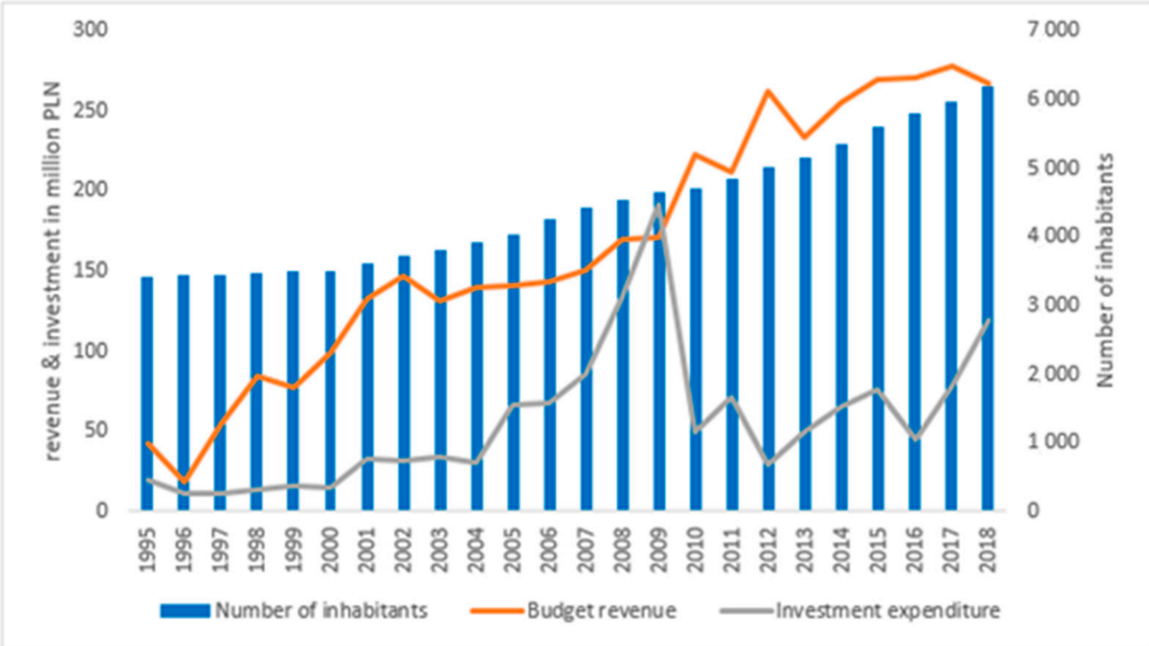

Figure 5. Budget revenue, investment expenditure (in millions of PLN), and population of the Kleszczów municipality in 1995–2018 (Source: own elaboration based on data from the Central Statistical Office and the Municipality).

An important element of our study is a GIS-based analysis, which makes it possible to compare relevant satellite images from two different time periods and draw appropriate conclusions. Thanks to such a method, it is possible to estimate the changes in land cover in a larger lignite mining area. For example, Figure 6 shows the Bełchatów opencast mining area in 1984 and in 2018, showing the location of scattered villages throughout the opencast mining area almost 40 years ago (when mining activity was still in its infancy) and in the relatively recent past (four years ago). From the images shown, it can be seen that the opencast mining activities led to the resettlement of five villages, namely Kuców, Stawek, Aleksandrów, Faustynów and Folwark, which means the resettlement of about 500 inhabitants. This process took place in the 1980s and early 1990s. Due to changes in the land use structure in the municipality and a deterioration in the conditions for agriculture, another 1000 inhabitants left the municipality during the same period. It is worth noting that this type of research method, based on the analysis of GIS, has been used before, e.g., in the study by Pavloudakis et al. [7], who compared satellite images for the lignite mining centre of Ptolemaida-Amyntaio in Greece.

Table 7 shows the land use structure in the municipality of Kleszczów. Comparing the current land use structure with that before mining, a clear change can be seen. The share of mining land in the total area of the municipality is now about 15%. On the other hand, the share of arable land has decreased from about 50% to 30%, which has enabled the expansion of the mine site and the development of residential and commercial areas, especially in the town of Kleszczów, which has become a modern local centre.

Figure 6. Bełchatów open pit area in 1984 (**left**), and in 2018 (**right**) (source: own elaboration).

Table 7. Land use structure in the municipality of Kleszczów.

Type of Land Use	Share in 2020	Share in 1980
Arable land	30.10%	50.70%
Forests and wooded areas	27.10%	36.40%
Mining areas	14.80%	0.00%
Permanent pastures	5.40%	5.70%
Industrial areas	4.00%	0.00%
Permanent pastures	3.70%	4.00%
Undeveloped, urbanised areas	3.70%	1.20%
Other	11.20%	2.00%

Source: own elaboration based on the Study on the conditions and directions of spatial development of the Kleszczów municipality (https://www.bip.kleszczow.pl/bipkod/011/004, accessed on 8 June 2022).

Significant changes in land use are also evident from the analysis of the corresponding orthophotos. Figure 7, created using software based on GIS, shows the change in land use between 1980 and 2020 in the municipality of Kleszczów. It shows a decrease in arable and forest land in the studied area. The southern part of the municipality is dominated by residential areas and industry, while in the central part the land is used for lignite mining. However, it should be kept in mind that the mining area will be reclaimed after the end of mining and converted into a forest or a water body with a recreational function.

From an agricultural point of view, the vast majority of soils in the municipality of Kleszczów are classified as IVa–VI, which means that they are not attractive, or more precisely, do not represent any value in the context of agricultural production. Table 8 shows the percentage share of the different soil quality classes in the total area of arable land in the municipality of Kleszczów. It shows that soils of classes IVa–VI account for over 90% of all soils in this municipality. The same applies to the overburden removed from the mines. Therefore, the allocation of part of the land for mining is not a great loss for the region, but on the contrary, can stimulate growth and allow diversification of land use towards urban use with residential and commercial areas.

Table 8. Percentage share of the different soil quality classes in the total area of arable land in the municipality of Kleszczów.

Land Cover (Classes)	Percentage
IIIa	1.20%
IIIb	8.40%
IVa	21.70%
IVb	17.10%
V	35%
VI	16.50%

Source: own elaboration based on data from the National Research Institute of Soil Science and Crop Production.

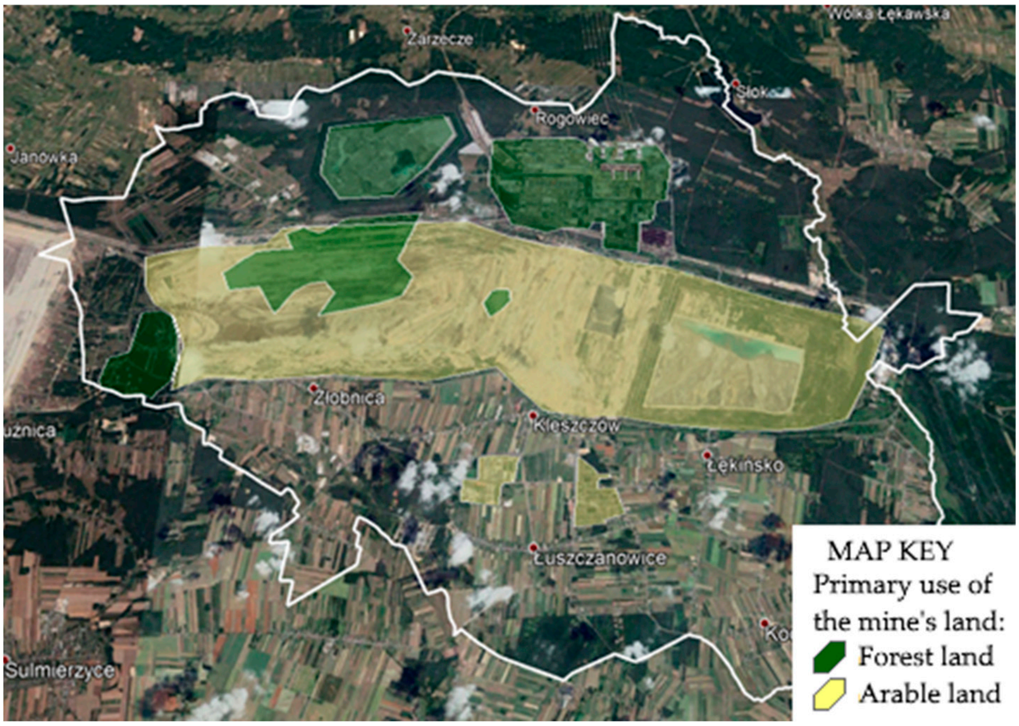

Figure 7. Change in land use in the period 1980–2020 in the territory of the commune of Kleszczów. Note: The white line marks the exact location of the open-cast lignite mine in the municipality of Kleszczów. (Source: own elaboration).

In order to obtain a complete picture of the environmental impact of opencast lignite mining, it is also important to emphasise the importance of mitigation measures, which in the case of Kleszczów are implemented in the following form [59]:

- Reduction of pollutants produced by coal combustion, in particular (1) dust reduction through the use of electrostatic precipitators (with a dust collection efficiency of 99.6%); (2) sulphur dioxide (SO_2) through the use of the flue gas desulphurisation method based on wet lime and gypsum (with an efficiency of 95%) and the production of gypsum as a by-product that can be used in the construction industry; (3) carbon dioxide (CO_2)—the power plant in Bełchatów has the lowest CO_2 emission rate per unit of electricity generated in Poland; (4) nitrogen oxides (SO_x), through the use of boilers with highly efficient denitrification equipment and the application of the SNCR method; (5) mercury, through the use of innovative mercury removal and disposal methods developed in cooperation with scientific centres,
- Mitigation of the effects of excessive soil drying in terms of the cone of depression [16,46,61], the extent of which is shown in Figure 8,
- Restriction on further use of land for non-agricultural and non-forest purposes, i.e., minimisation of further use of land for lignite mining activities,
- Adequate management of water resources (both drainage and irrigation)—construction of a network of canals and pumps to allow drainage of the mining area while irrigating surrounding areas affected by excessive drought, construction of sedimentation basins for treatment of water used during mining operations,
- Reclamation and improvement of the use value of soils, in particular the storage of humus material, the fertilisation of dumps, the neutralisation of acids or the remediation of alkaline and saline soils, the isolation of contaminated soil formations,
- Preservation of the landfill site through appropriate storage of potentially hazardous wastes within the landfill area, terracing of slopes, provision of biological cover,
- The rehabilitation of mining areas after their closure through appropriate technical and biological rehabilitation measures at the mines and external tailings piles aimed at

making them safely usable again and restoring the lost beneficial and natural values, including the creation of water reservoirs in the post-mining landscapes, fertilisation and planting of the tailings piles and their use for recreational purposes.

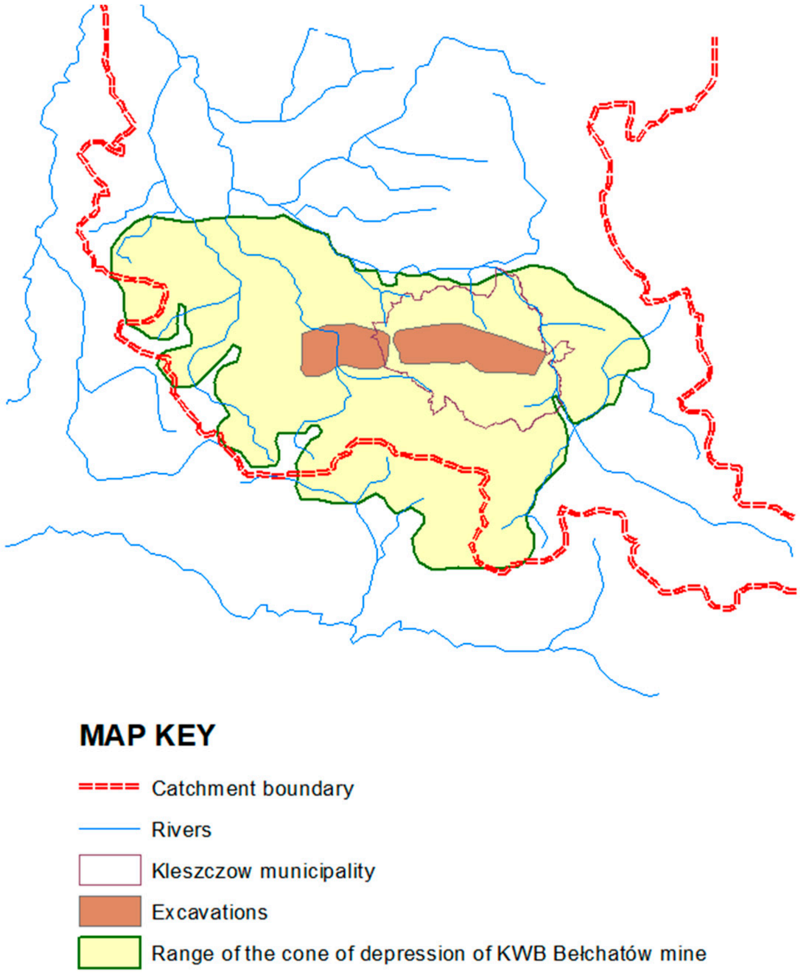

Figure 8. Extent of the subsidence cone of the KWB Bełchatów mine (source: own elaboration based on data from the assessment of runoff changes in the Widawka river basin).

In summary, while the negative impacts of opencast lignite mining on the environment and the local landscape should not be underestimated, it must also be taken into account that it is possible to significantly reduce the harmful impacts of mining activities, especially if appropriate steps and measures are taken to prevent damage and an adequate rehabilitation plan is prepared and implemented.

In turn, the analysis of socio-economic indicators shows that immediately after the start of lignite mining activities, there was an initial decline in the population and destabilisation of the local labour market. It is worth noting that the number of inhabitants had initially decreased since the beginning of mining (in 1977 there were 5300 inhabitants, in 1990—3736 and in 1995—as shown in Figure 5—only 3429). Shortly afterwards, in the 1990s, the number of inhabitants steadily increased. The municipal budget revenue also increased considerably (as shown in Figure 5). The taxes and levies paid by the mine and the power plant, as well as the newly created industrial and service centres, have contributed to a dynamic increase in revenues in the municipal budget (almost PLN 280 million in 2017). When analysing this development, it should be noted that as budget revenues increased, the municipality was also able to increase its investment expenditure (as shown in Figure 5). The funds spent have helped finance, for example, the provision of services, education, health, culture and technical infrastructure in the region.

Between 2005 and 2018, the investment expenditure of the Kleszczów municipality was over PLN 50 million per year, reaching a peak of over PLN 190 million in 2009. These funds were used for the expansion of the road network, free medical and dental clinics, educational facilities (including three kindergartens, two primary schools, a secondary school, a junior high school, a high-tech grammar school), a cultural centre (Gminny Ośrodek Kultury, Sportu i Rekreacji), a sports club (LKS KNAUF Kleszczów), the educational and sports centre "SOLPARK", local industrial estates, the Kleszczów Business Incubator and its own electricity, gas and telecommunications networks. A series of outstanding investments and innovations realised by the municipality of Kleszczów earned it numerous prizes and awards, including the title of the best municipality in Poland, first place in the ranking of municipal investments and the title of the innovative municipality [62]. As a result, the municipality has become the region's main industrial centre, but also a beacon of innovation and a model for rural community development. Unlike many other rural municipalities, the population of Kleszczów grows year after year, thanks to newcomers attracted by the employment opportunities and the rich educational and cultural offers.

It is also worth noting that the municipality of Kleszczów has developed extensive plans for the reclamation of the mine site, to transform it into a forest, a reservoir and a recreational area (due to the low productivity of the local soils). The objectives of these plans are (1) to improve the environment, and (2) to create an alternative source of income after the mine closes, e.g., through tourism [63–65]. A significant part of the mine is to be converted into a water reservoir for recreational purposes with appropriate infrastructure. The remaining part of the mine and the external spoil heaps are to be rehabilitated through afforestation, which has already been done to some extent. It is assumed that agriculture currently has only a supplementary function in the municipality (Figure 9). However, thanks to the measures described above, the municipality can become not only environmentally friendly but also attractive to tourists.

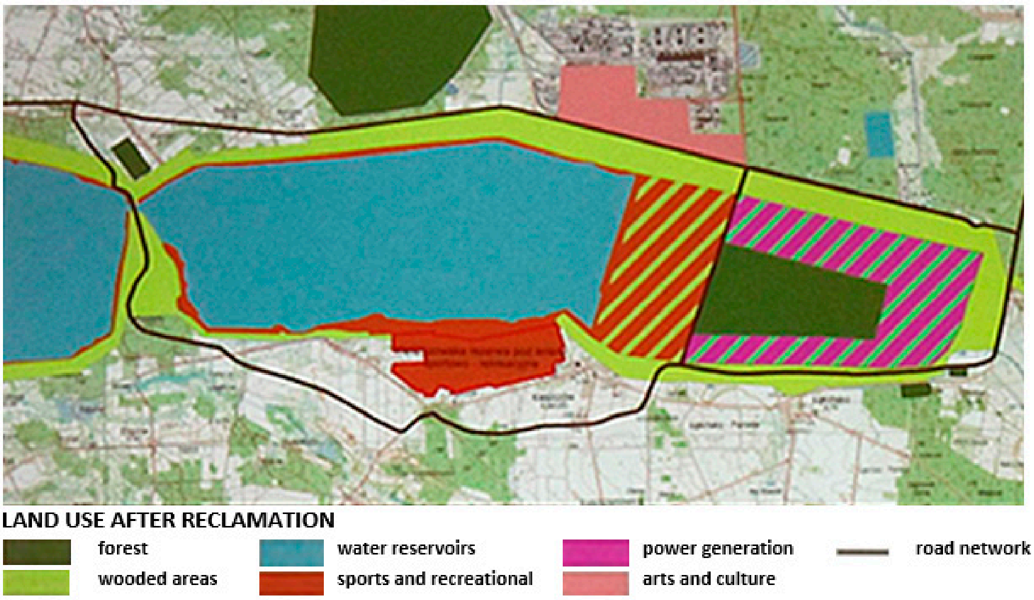

Figure 9. Planned land uses after the recultivation of the KWB Bełchatów mine in the municipality of Kleszczów (source: materials from the Kleszczów Municipal Office).

To further substantiate our findings and show the actual impact of lignite mining on vegetation, we use the widely used Normalised Difference Vegetation Index (NDVI) and data from two different time points (years 1985 and 2021) from LandSat 9 to illustrate a change in land cover over time. The NDVI is a simple indicator based on remote sensing measurements that can be used to assess whether or not the observed target contains living green vegetation. Figure 10 shows the same relevant fragment of the Kleszczów municipal area known as the Góra Kamieńska, which is located on the right side of the main open-cast lignite mine (and represents part of the forested inner dump of the Bełchatów field). Góra Kamieńska is an artificial hill, 405.6 metres above sea level, created as an outer dump of the Bełchatów opencast lignite mine. It is evident that the NDVI in the rehabilitated area of the former landfill reaches high positive values, indicating that the area has been afforested and the indicators have improved. More specifically, the extent of the quarry itself has increased and here the NDVI reaches negative values, but given the reclamation and future development, it is expected that the NDVI in this area will increase significantly.

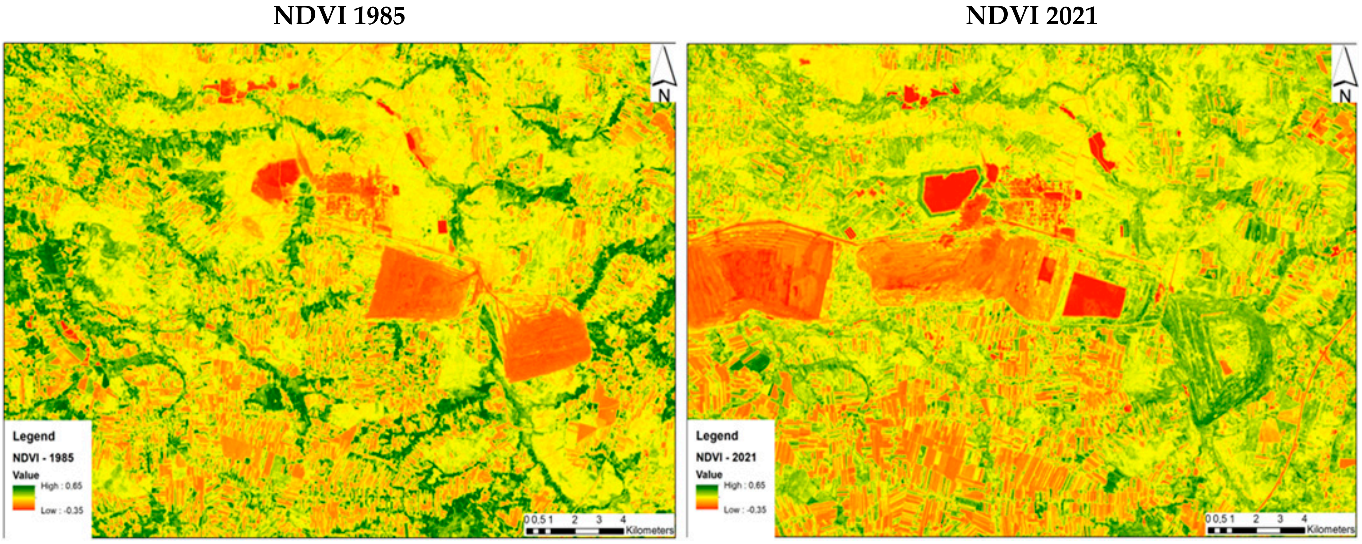

Figure 10. Comparison of NDVI in 1985 and 2021 for the same area of the municipality of Kleszczów (appx. 670 km^2). (source: own elaboration based on LandSat data).

The following is a summary of the evidence of the positive impact of lignite mining on the functioning and development of the municipality of Kleszczów:

- Approximately 18,000 skilled workers employed by companies in the municipality;
- Large deposits of natural resources associated with lignite mining (clays, sands, aggregates, lake chalk);
- Significant quantities of synthetic gypsum, which is in demand by building material manufacturers;
- Large opportunities for potential investors to purchase electricity through the municipal grid;
- Significant impact of the mine and power plant on the technological, financial and social development of the district and the region as a whole;
- Creation of potential for further development of industry and services through the creation of prepared investment areas (Kleszczów Industrial Zones);
- Possibility of granting tax exemptions for new investors;
- Above-average healthcare system (e.g., visiting specialists, four free dental surgeries);
- Very well-developed educational, cultural and sports facilities. The educational and sports complex "SOLPARK" is fully financed from the municipal budget;
- Provision of kindergarten places for all children of pre-school age;
- Free meals for all pupils in the municipal schools;
- Water supply available in the whole area (i.e., 100%) of the municipality;
- All municipality inhabitants (i.e., 100%) have full access to all basic utilities such as gas, electricity, water and sewer network and ICT network;
- Own gas network throughout the municipality—construction of a reduction station and a gas pipeline supplying gas from over 30 km away;
- Wastewater collection and treatment—90% of the municipality area (wastewater network supplemented by individual waste water treatment plants);
- Municipal energy system operated by a local operator (supplies energy to a large part of the municipal area and industrial areas);

- Municipal ICT network operated by a local operator (provides connectivity and internet access to all interested users);
- Developed network of municipal and district roads with pavements and cycle paths;
- Municipal Industrial Zones—the first zone in Poland with such a status.

Finally, it is also worth highlighting some important facts about the protective measures for the environment, especially those concerning the mitigation of the harmful effects of emissions from the combustion of lignite at the Bełchatów power plant:

(a) Each of the boilers at the Bełchatów power plant is equipped with electrostatic precipitators that capture the dust generated during lignite combustion. The dust collection efficiency is 99.6%. Dust emissions were reduced by 97%—from 35,000 t of dust in 1989 to 0.9 t in 2017.

(b) A wet lime-gypsum method of flue gas desulphurisation with an efficiency of 95% was selected and used, with gypsum as a by-product. To increase the efficiency of the flue gas desulphurisation process, additional flue gas desulphurisation (FGD) units are currently being upgraded to achieve SO_2 emission levels below 130 mg/Nm^3. The Belchatow power plant has reduced sulphur dioxide emissions by 90%, from 400,000 t in 1989 to 39,000 t in 2017.

(c) In 1992, primary methods to reduce NO_x emissions were introduced at Bełchatow Power Plant by optimising the combustion process to reduce emissions of nitrogen compounds. In order to reduce NO_x emissions even more (to levels below 175 mg/Nm^3), the boilers are currently being successively equipped with highly efficient denitrification systems using the Selective Non-Catalytic Reduction (SNCR) method, which reduces emissions by dosing urea. As a result of the measures taken so far, NO_x emissions at Elektrownia Bełchatów have been reduced by 48%—from 55,000 t of NO_x in 1989 to 29,000 t in 2017.

5.2. Case Study 2—Kleczew Municipality

As far as the municipality of Kleczew is concerned, the socio-economic indicators show similar trends to those of the municipality of Kleszczów, i.e., increasing municipal budget revenues and an accompanying increase in investment expenditure (see Figure 11).

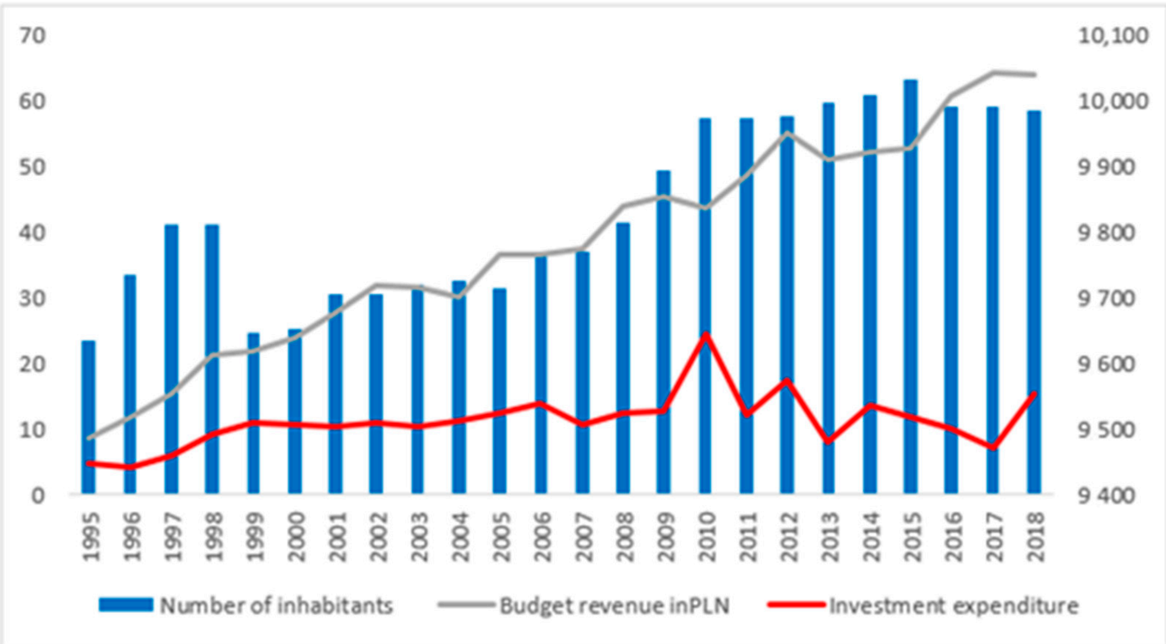

Figure 11. Budget revenue, investment expenditure (in millions of PLN), and population of the Kleczew municipality in 1995–2018 (Source: own elaboration based on data from the Central Statistical Office).

The increase in public spending is best illustrated by data from 2010 when the Kazimierz open-cast mine ceased its operations. Between 2000 and 2018, the municipality's investment expenditure fluctuated between PLN 10–15 million per year. In 2010, it peaked at over PLN 24.5 million (Figure 11). The lower production of the mine compared to Bełchatów and the resulting lower revenues for the budget did not allow for such far-reaching investments as in the municipality of Kleszczów, but this does not mean that they were completely abandoned. The municipality of Kleszczów was able to realise investments such as a well-developed road network, a bypass road, a water supply and sewage system serving most of the municipality, medical clinics, two kindergartens and five primary schools. One of the largest investments was the construction of a sports and recreation park in Kleczew, which was built on post-mining land as part of the initiative "Revitalisation of post-mining landscapes around a lake in the municipality of Kleczew". In the coming years, the construction of cultural facilities, a nursing home for the elderly and a Tyrolean crossroads are planned. The municipality wants to become the centre of the region and attract tourists and investors. However, due to the end of lignite mining and the planned closure of the second open-cast mine, no significant increase in the number of inhabitants is currently expected, so the population will likely remain at around 10,000.

It is also worth taking a look at the comparison between the two investigated municipalities in terms of their soil structure. The municipality of Kleczew, unlike the municipality of Kleszczów, has a much more favourable soil structure and greater potential for land reuse. For this reason, much of the area has retained its agricultural character, as can be seen in Table 9. The soil structure in the commune of Kleszczów is dominated by soils of medium and poor quality: Luvisols, Cambisols (brown soils), leached Eutric Cambisols and Umbric Gleysols. Currently, wheat complexes account for 2% and rye complexes for 95% of the soils suitable for agricultural production.

Table 9. Land use structure in the municipality of Kleczew.

Type of Land	Share in 2020
Arable land	70%
Mining land	12%
Land under water	4%
Built-up areas	4%
Transport infrastructure	3%
Derelict land	3%
Forests and wooded areas	2%
Other	2%

Source: own elaboration.

Furthermore, after analysing the environmental monitoring data and the data from GIS, it can be concluded that there is no evidence of catastrophic impacts on the studied areas, especially those that would result from the activities of the existing open pits. The mine site is adjacent to farmland whose vegetation condition indicates high yields (Figures 12 and 13).

Thanks to the remedial measures initiated by the municipality of Kleczew, the negative impact of mining on the environment has been reduced, also with regard to the further activities related to the life cycle of lignite. It should be noted that in 2015 the municipality of Kleczew adopted an action plan to reduce carbon emissions. The opencast mine also meets all the required environmental standards for lignite mining. Mine water is treated in underground sedimentation basins by sedimentation of suspended mineral matter. Dust deposition is measured regularly at selected points throughout the year. Noise pollution is also measured every two years at specific measuring points to ensure that permissible limits are not exceeded.

Figure 12. The Kazimierz and Jóźwin open pits in 2015 (source: Google Earth).

Figure 13. Arable land in the immediate vicinity of the Jóźwin open-cast mine (source: KWB Konin materials).

What adds to Kleczew's strategic importance and gives it a significant competitive advantage is its convenient location in relative proximity to Konin (20 km away), a city of 80,000 inhabitants that serves as the centre of local services for Kleczew residents and is the central city of the region. Due to its proximity to this town, the Kleczew mine has proven its potential as a weekend destination for Konin residents after its partial rehabilitation. Therefore, the planning of further reclamation works and new functions for the Kleczew post-mining area focused on tourism and recreation (Figure 14). Ultimately, the following combination of land uses is planned for this area [66,67]:

- Agricultural use—both opencast lignite mines can be recultivated for growing wheat, beet, rape, sunflower or maize, which can be grown on shallow upland soils; after appropriate soil rehabilitation, agricultural production can even be more effective than on the original sandy soils of the Konin region.
- Forest use—many hectares of forest have been planted on the dumps of the closed and active opencast mines, where various animal species find excellent living conditions; further dumps are to be afforested.
- Water use—the water reservoirs in the post-mining landscape are mainly used for recreation, but also have a retention function. They are well integrated into the landscape of the region and have significantly increased tourism potential, as in the case of the quarry pond created on the former Kazimierz Północ field.
- Recreational use—the post-mining landscape of Józwin IIA has already been transformed into a recreational centre by decision of the municipality of Kleczew. The recreation and sports park created in 2013 is a central point overlooking the mining lake and is surrounded by numerous recreational facilities. Other planned changes will be introduced gradually.

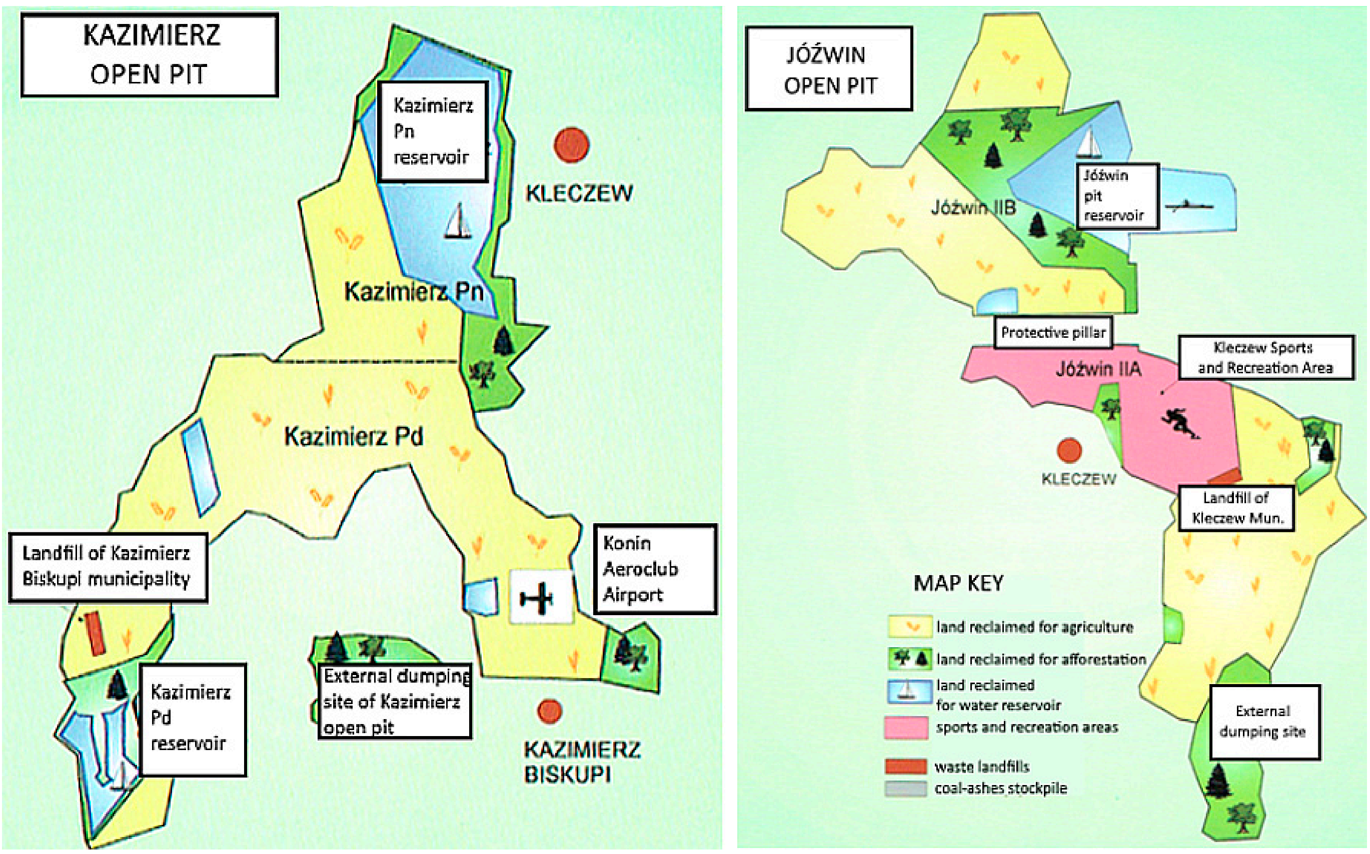

Figure 14. Post-mining land uses after the reclamation of "Kazimierz" (**left**) and "Józwin" (**right**) open pits [17].

5.3. Socio-Economic Analysis of the Data

Sections 5.1 and 5.2 provide relevant socio-economic data that shed light on the development of the studied lignite mining municipalities. Although the visual assessment of the data based on Figures 5 and 11 suggests that both the increased budget revenues of these municipalities and their investment expenditures are attracting new residents, it is worth examining from an analytical and statistical point of view whether there is evidence that this is indeed the case.

For the analysis, we use annual data from 1995–2018, in particular data on the number of inhabitants (response variable) and the budget revenue and investment expenditure (explanatory variables) for the two municipalities under study (i.e., Kleszczów and Kleczew). The aim is to test the relationships between the data and, in particular, to investigate whether the improvement of economic conditions in the two lignite mining municipalities has an impact on the population of these municipalities. This is a simple analysis to support the visual assessment of Figures 5 and 11. The study could, of course, be extended by including some additional variables in the model, but we do not want the econometric analysis to dominate the findings presented in our study. In other words, our study is largely based on the evaluation of case studies, stylised facts and remote sensing indicators, and the results of the models presented in this section only reinforce these findings.

We tested all correlation coefficients (for each pair individually) and found that all corresponding p-values were less than 0.05 (Figure 15). This is an indication that the correlation estimates between the variables studied are statistically significant. However, it must be taken into account that we are dealing with a time series, so the reliability of such tests is weaker than with cross-sectional data.

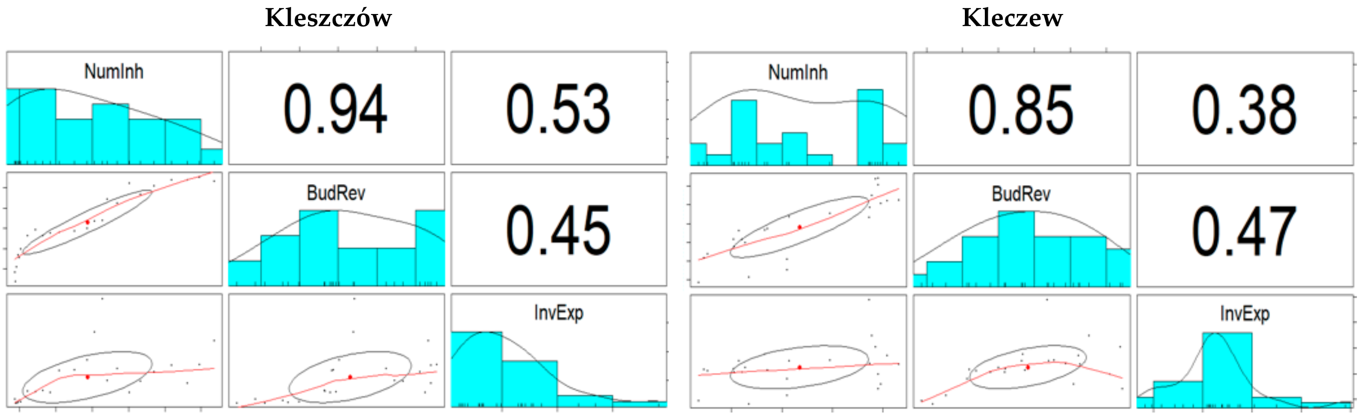

Figure 15. Pairwise correlations for the number of inhabitants (*NumInh*), budget revenues (*BudRev*) and investment expenditure (*InvExp*) (source: own elaboration in R Studio).

The pairwise correlations between the variables studied do not imply causation. It is difficult, on the basis of the above results, to answer unequivocally whether increased municipal budget revenues and increased expenditure (as a result of increased lignite mining), unambiguously cause an increase in the number of inhabitants, which would confirm our research hypothesis that opencast lignite mining positively activates local communities. There are many indications that this might the case. The confirmed results of the correlation coefficients give an indication that this is indeed the case. Therefore, to be sure, one should use the Granger causality test to see if, in fact, one variable is useful in forecasting another [68] and, more specifically, whether the variables Budget Revenue and Investment Expenditure provide statistically significant information about future values of the Number of Inhabitants in both studied municipalities where lignite is mined. By relying on the Granger causality test and running all tests including the Granger causality tests in reverse, we could only confirm that knowledge of the values of the number of inhabitants is valuable in predicting the future values of investment expenditure [F = 5.6021, Pr(>F) = 0.009755]. At the α = 0.05 level of significance, it could not be confirmed that neither the values of budget revenues nor investment expenditure predict the number of inhabitants in the future [F = 2.3882, Pr(>F) = 0.08402, and F = 0.8771, Pr(>F) = 0.4615, respectively]. Since we could not provide evidence of causality to conclusively clarify the assessment of the association of the variables under study, we conducted a brief examination of the panel regression analysis, ordinary least squares (OLS) and fixed-effects model specifications.

In the model, the number of inhabitants is estimated using panel regressions. Municipalities are represented as panels and subsequent years as time. The pooled OLS specification assumes that there is no heterogeneity between municipalities, which is expressed by using the following equation: $NumInh_{it} = \alpha + \beta X'_{it} + e_{it}$, where $NumInh_{it}$ denotes the number of inhabitants corresponding to each of the municipalities and is log-linearised to adjust for disparities, better explore their dynamic properties and simplify the calculations [69,70]. In other words, $i = 1, 2$ refers to the number of individual municipalities recorded in the database, and $t = 1995 \ldots 2018$ refers to consecutive years. The term α is the common intercept, X' is the vector with the predicting variables, which means that a specific set of control variables is used to obtain the results. The same predictors are used in all models, i.e., budget revenue (*BudRev*) and investment expenditure (*InvExp*). Moreover, the term e_{it} included in the model presented above is the error term. The specification FE with fixed individual effects is expressed by the following equation: $NumInh_{it} = \alpha_i + \beta X'_{it} + e_{it}$, where α_i represents the fixed effects of each municipality. It controls for heterogeneity between municipalities. The difference between the specification of FE and the OLS model is that the former, unlike the latter, reflects community effects, which are reflected in the α_i term. Therefore, α_i can be viewed as ignorance about all of the other systematic factors that predict the *Number of Inhabitants*, other than X'. Tables 10 and 11 show the results, and more specifically Table 10 shows the Fixed Effects model specification, and on top of that, Table 11 reflects the dummy variables (municipalities studied) and their contribution to the explanation of the total variability of the response variable. The model that was created is relatively simple and contains only two explanatory variables. All this was completed to keep this study relatively simple and not to further complicate its meaning.

Table 10. Fixed Effects panel regression model.

Predictor	Estimate	Std. Error	t-Value	Pr(>|t|)
Budget Revenue	0.096977	0.032791	2.9574	0.004974 **
Investment Expenditure	0.082478	0.031710	2.6010	0.012613 *
Observations		48		
R^2/R^2 adjusted		0.531/0.499		

Note: Significance codes: ** 0.01 * 0.05. Source: own elaboration in R Studio.

Table 11. Least-squares dummy variables (LSDV) model.

Predictors	Estimates	CI	*p*-Value
Budget Revenue	0.10	0.03–0.16	0.005
Investment Expenditure	0.08	0.02–0.15	0.013
Municipality [Kleczew]	6.18	5.31–7.04	<0.001
Municipality [Kleszczów]	5.11	4.17–6.05	<0.001
Observations		48	
R^2/R^2 adjusted		1.000/1.000	

Note: CI stands for confidence interval. Source: own elaboration in R Studio.

As for the specification of the fixed effects (FE) panel regression model is presented in Table 10, the *F* test showed that it is superior to OLS (F = 549.83, df1 = 1, df2 = 44, *p*-value < 0.00000000000000022). All variables were logarithmically transformed. The logarithmic transformation of the variables in the model has some important advantages [69,70]. In general, a regression model without transformation has unit changes between the explanatory and response variables, where a unit change in an independent variable coincides with a constant change in the dependent variable. Taking the logarithm of one or all variables, the case changes from a unit change to a percentage change. Since the p-value < 0.05, the FE model is the better choice compared to the OLS model (F = 549.83, df1 = 1, df2 = 44, p-value < 0.00000000000000022). Unfortunately, it is not possible to build a random effects (RE) model specification because the model is not estimable. In particular, more cross-sectional data are needed for the Swamy-Arora random effects model to be estimated (these assumptions are not met) [70].

More specifically, the results (Table 10) show that the variables Budget Revenue (*BudRev*) and Investment Expenditure (*InvExp*) positively influence the variable number of inhabitants (*NumInh*). Both variables in the model have beta coefficient estimates greater than zero, which are also statistically significant.

In turn, the least square dummy variable (LSDV) model shows how other individual factors for each community further influence the response variable (see Table 11). The model shows that about half of the variation in the endogenous variable can be explained by the variation in the other factors and economic variables analysed (R^2/R^2 adjusted adjusted are 0.531/0.499).

Moreover, the results prove that a considerable part of the variation in the endogenous variable can be explained by fixed effects. In the case of the municipality of Kleczew, these effects are obviously larger, as the extent of lignite mining there is also larger compared to Kleszczów.

6. Discussion

The rationale for this study is partly justified by the existence of similar studies conducted for other large lignite-producing countries, including Germany [45,48,71] and Greece [7]. As for the novelty of our study, LandSat 9 satellite data (or more precisely GIS remote sensing data) from different periods are its important element. One cannot say that there is a complete lack of remote sensing studies on lignite mining areas in Poland, but there are certainly not many. We have not found a comparable study that takes into account the Polish context of lignite mining and, for example, uses NDVI data from two very distant time periods (i.e., the present and the 1980s) and draws conclusions from them. Our study shows the extent of environmental changes in the Polish context as far as lignite mining is concerned. This type of research, based on the use of remote sensing data, is becoming increasingly popular. It allows the processing and analysing of satellite images (orthophoto maps), and drawing conclusions from different fields of knowledge, e.g., climate change and water-related issues as in the study by Sobieraj et al. [72], where digital elevation/terrain and slope maps were used and some conclusions were drawn on this basis [72]. We believe that this type of study will become more popular due to the development of remote sensing technology and the increasing amount of available data and tools for data processing and analysis. In this context, Zawadzki et al. [73] point out that post-mining landscapes are usually very large and their land cover is not easy to assess due, among other things, to the particular spatial variability associated with different environmental factors. Therefore, the application of an appropriate survey method to assess such areas is all the more important. The method on which such a study should be based should not only allow a reliable assessment (without excessive errors) based on available data for relatively large areas but should also be cost-effective and offer the possibility of obtaining reliable results relatively quickly [73–75]. Modern remote sensing and geostatistical methods help in conducting such studies [75]. One such method is the use of orthophoto maps, which are produced based on various remote sensing sensors, have an adequate spatial, radiometric and temporal resolution, and cover large areas [73]. Such satellite orthophotos can provide a variety of data, e.g., geophysical, ecological, geochemical or even biological or social in nature, which can form a solid basis for validation of the collected satellite data and for scientific conclusions based on geostatistics [75] and a variety of very sophisticated tools such as the Google Earth Engine [76,77]. An example of the use of remote sensing data can be the calculation of selected indices of land surface temperature or vegetation production [78,79]. D'Emilio [75] and Zawadzki et al. [73] point out the possibility of combining numerous ground-based measurements with satellite information originating from Sentinel, Landsat or other satellites to use these data in an integrated way.

Przeździecki et al. [74] investigated the state of grassland moisture in the area of an extensive neighbourhood of an open-cast lignite mine using the Thermo Vegetation Drought Index (TVDI). For this purpose, the authors exclusively used a remote sensing method based on Landsat imagery; they estimated the spatial variability of the TVDI using a semivariance analysis. They thus proved that remote sensing and the TVDI analysis based on it can serve as an effective indicator of the moisture status of grassland in the vicinity of opencast mining. Zawadzki et al. [80], on the other hand, used remote sensing (more precisely, data from TM and ETM+ sensors of the Landsat 5 and Landsat 7 satellites) and geostatistics to determine the area of influence of a subsidence cone near one of the largest opencast mines in Bełchatów. Moreover, the remote sensing-based estimation of the area of the subsidence cone provided similar results as the ground-based data. However, it is worth mentioning that the application of a remote sensing-based method to a very large area (40 km) provided significant savings, as remote sensing is much cheaper compared to ground-based methods.

Our remote sensing study of the NDVI index in the lignite mining area of the Kleszczów municipality, based on Landsat data, should also be seen in this context (i.e., savings in carrying out the analysis) (see Figure 10). Figure 10, indeed shows that the NDVI in the rehabilitated area of the former landfill reaches high positive values after reclamation, which clearly shows that the area has been afforested and the indicators have improved. Of course, the extent of the quarry itself has increased—and here the NDVI reaches negative values, but in view of the reclamation and future development, the NDVI in this area can be expected to increase significantly. This study should be seen as an additional extension of the empirical findings in the field of the GIS-remote sensing analysis (LandSat data) in connection with environmental changes in lignite mining areas after mining.

As for the cost-benefit ratio in the life cycle of lignite (for the mining municipalities studied), the study considered both socio-economic and environmental factors. Specifically, the study is based on desk research, i.e., the analysis of data from the Central Statistical Office (CSO) and the municipalities of Kleszczów and Kleczew, as well as on geographic information systems (GIS), which enable the integration and joint analysis of geodata from different sources, including satellite imagery (i.e., Landsat data). In other words, GIS enables the analysis of data derived from maps from different time periods, and the integration of location data (in the case of this article, data on open pit mines in two different municipalities in different voivodeships) with all kinds of descriptive information. Within the data types of GIS, the images we use are a powerful visual aid and serve as a source of information, e.g., for classification schemes showing land use/land cover. Desk research analysis involves the examination, evaluation and processing of information already collected from official sources. We refer in particular, to data from local branches of the Central Statistical Office, various reports [81,82], data from municipalities, including municipal spatial planning studies, and data obtained through private communication with mine and community representatives [36,56].

As for the statistical and econometric analysis conducted in Section 5.3, it shows that an improvement in economic indicators related to budget revenues and investment expenditure of lignite mining municipalities has a positive impact on the number of inhabitants living in these municipalities. Although it was not possible to prove causality for the relevant variables, an examination of the panel regression analysis shows that about 50% of the variation in the number of inhabitants variable can be explained by the variation in the lignite mining municipalities' budget revenues and investment expenditure variables. Furthermore, the estimated beta coefficients were found to be positive and statistically significant. It can therefore be concluded that the finances (better economic conditions) of lignite mining municipalities (most of which come from lignite mining) promote the growth of the population in these regions. The overall dimension of the study suggests that the positive aspects of mining predominate in both municipalities studied. In the case of the Kleszczów municipality, the land designated for mining was mostly low-grade farmland. Although the number of inhabitants in the municipality decreased after mining started, this trend reversed after a few years. The municipality's income and thus its investment expenditure began to increase significantly. This once poor rural municipality is now the richest municipality in Poland and its current level of development is in many ways comparable to that of cities. Moreover, the carefully planned reclamation and future use of the mining areas aims to strengthen both the tourism and economic potential of the region [83]. With the introduction of more restrictive environmental policies that limit the emission of air pollutants and reduce the extent of the groundwater drawdown cone, lignite mining in the municipality of Kleszczów is no longer seen as a problem, but as a source of income, and the municipality itself as an attractive place to live that sets standards for the development of other regions.

Similar trends as in Kleszczów can also be observed in Kleczew. Although the extent of mining in the municipality of Kleczew is much smaller compared to Kleszczów, the same positive and negative aspects of lignite mining can be observed when looking at the ratio of the mining area to the total administrative area. In both municipalities, there is a systematic increase in population and municipal budget revenue, and consequently an increase in investment expenditure. Although the municipality of Kleczew has largely maintained its agricultural character, the income from mining has enabled numerous investment projects to be carried out. Furthermore, the extent of current environmental problems is relatively low, due to the implementation of the Low Emission Management Plan, the limitation of the extent of the subsidence cone (so that farmland is actually adjacent to the mine site, as previously shown in Figure 13) and the implementation of ongoing reclamation measures after the mining of part of the deposit.

Opencast lignite mining thus has both negative and positive impacts on the municipalities, which are briefly summarised in Table 12. This applies not only to lignite mining but also to rock or sulphur opencast mining. However, the analysed examples of two municipalities show that it is possible to ensure energy stability for the whole country and rural development if the negative impacts of lignite mining are adequately mitigated and mine sites are properly rehabilitated after closure.

Table 12. Advantages and disadvantages of opencast mining in rural areas.

Advantages	Disadvantages
Increased revenue for the municipal budget	Abandonment of agricultural use of rural areas
Increased development opportunities for the municipality	Cone of depression
Development of local entrepreneurship	Deforestation
Increased prosperity of the local population	Air pollution
Reduced unemployment rate	Damage caused by mining
Reduction of the phenomenon of economic migration of the young generation	Formation of mining dumps
Development of local infrastructure and improved access to basic utility services	Domination of the local economy by only two sectors: mining and energy
Construction of cultural and sports facilities, development of local economic zones	The need to resettle the population
Ultimately, an increase in the tourist attractiveness of the region	Traffic problems
Use of mining by-products	Landscape change
Possibility of using the extracted material (lignite) for rehabilitation	Initially a decline in the municipality's attractiveness for tourism (at the beginning of opencast mining)

Source: own elaboration.

7. Conclusions

The study examines the changes taking place in rural mining areas as a result of open-cast lignite mining in Poland. More specifically, the aim of the study was to assess the possibility of continuing opencast mining and its impact on rural development—both from an environmental and socio-economic point of view. To establish this, we have combined different research methods based on case study analyses (for two important lignite mining centres in Poland), a number of different stylised facts, GIS remote sensing analyses (e.g., NDVI for part of the Kleszczów municipal area) and econometric analyses for selected socio-economic data (based on correlation tests, panel regressions and Granger causality tests). The study took particular account of the suitability of the excluded areas for agricultural production. Our results show that in some cases mining promotes community development and furthermore leads to new agricultural and tourism potential after recultivation. Thanks to mining, rural municipalities are changing their character and combining agricultural, industrial and other economic activities.

It is worth noting that the decision for or against lignite mining development and the assessment of its feasibility is of course strongly influenced by the nature of the municipality, the land use pattern and other social, economic and environmental aspects. Effective decision-making may require appropriate multi-criteria analyses of spatial data using the GIS software that takes into account all aspects of sustainable development. These analyses should also consider the social aspects related to resettlement.

Furthermore, hasty top-down decisions based on the assumption that mining is always and exclusively a harmful activity should be avoided at all costs. The low cost of energy production from lignite makes it the only energy source that can ensure Poland's self-sufficiency in energy [17]. In addition to providing the needed energy or rock material, opencast lignite mining has proven to be a development opportunity for the municipalities where the opencast mines are located. If mining is cost-effective and the ratio of overburden to deposit thickness does not exceed 12:1 [57,84], then mining is an option worth considering. In any case, mining should be carried out in an environmentally sound manner and should not damage protected unique ecosystems. The positive impacts of mining at some sites may outweigh the negative impacts. Ultimately, important decisions about starting or stopping mining activities in a region should always be made taking into account the views and situations of both the local population and the people working in the mines. Any decision taken by the government without consulting the miners may lead to increased tensions and protests, as has been the case all too often in Poland in recent years. Ensuring decent living conditions for the people who are to be relocated, and maintaining jobs for those who have migrated to work in the mines is a priority that cannot be ignored. Therefore, the negotiations between the government and the miners, as well as the special coal law mentioned in the introduction section, must be evaluated in light of the conclusions formulated above. If a lignite deposit can be considered important for the national economy and its mining is carried out in accordance with the principle of sustainable development and with consideration for the environment, such mining may not only be harmless but even beneficial for the development of the region.

Prospects for further research could include analysing opportunities for post-mining landscape development in places where exploitation has ceased, and monitoring directions for effective reclamation and development that are consistent with municipal and regional spatial planning policies. Guidelines established in this way can help local authorities consciously shape space by enabling the use of existing resources within their municipal areas and then giving them a new character based on mined resources and concern for the environment. In addition, it is advisable to explore the use of lignite outside the energy sector in various other areas as part of the inevitable energy transition. One of these areas is undoubtedly agriculture in the broadest sense. The lignite found in Poland is very similar to soil humus in its physical and chemical properties, with a high content of humic acids and functional oxygen groups. Therefore, most lignite deposits on the Polish territory have proved useful for agriculture and environmental protection, and fertilisers and recultivation mixtures have been developed on their basis. Further research should be directed towards the use of lignite fertilisers, including in the recultivation of industrially contaminated and degraded soils.

Finally, the practical value of the study is that it shows how rational exploitation of fossil fuels through opencast mining, using lignite as an example, complemented by properly implemented reclamation and rational land use, can contribute both to the energy security of the country as a whole and to the spatial development of local mining communities. Based on these conclusions, local authorities can make a conscious assessment of the resources available in their community area and the opportunities for their extraction. They can also gain valuable insights into what developmental changes they can expect in the long term in connection with such mining activities.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Below, in the form of Table A1, we give an overview of the most important works/studies dealing with the subject of this study. Our aim is to briefly characterise these works and present their contribution to the understanding of the analysed problems related to opencast lignite mining and its socio-economic and ecological significance.

Table A1. Important works/studies dealing with opencast lignite mining and its socio-economic and ecological significance (scientific approach).

Authors	Subject (What It Is Pertaining)/Area	Contribution/Details
Markandya et al. [3]	Analysis of the net impact of the transformation of the EU energy sector on future employment.	Markandya et al. [3] proposed various job creation measures as part of the transition to a green economy, including so-called green jobs. The authors analysed the net impact of the transformation of the EU energy sector on future employment, focusing on the so-called externalities and using a multi-regional input-output model. The results of the study show that the net employment created by the energy transition in the EU means 530,000 additional jobs in the EU (0.24% of total employment in 2009). A significant part of this is the so-called cross-border effects in the EU, i.e., the jobs created in one country come at the expense of a decrease in employment in other countries. Interestingly, the authors identified Poland as one of the main beneficiaries of the transformation of the energy sector.
Pavloudakis et al. [7]	Analysis of land use and land cover change based on supervised classification and geo-information system (GIS) and LandSat satellite data for different time periods.	Pavloudakis et al. [7] focused on indicating land cover changes in the wider lignite mining area for the Ptolemaida-Amyntaio lignite centre in Greece. These authors used an interesting research method, namely geographic information system (GIS) and remote sensing (RS), relying on data from two different periods, more precisely Landsat data for both periods. With these methods, they were able to extract multispectral images and then perform supervised classification of these images. With these methods and data, the authors were able to visually represent the growth of mining areas, changes in land use and land cover, and environmental changes.

Table A1. *Cont.*

Authors	Subject (What It Is Pertaining)/Area	Contribution/Details
Wójcik-Jurkiewicz et al. [1]	Analysis of the conditions that must be met in order to fully implement decarbonisation in Poland (as an element of a sustainable energy strategy), which the authors believe is necessary.	According to the authors' findings, decarbonisation on a larger scale in Poland and the introduction of low-carbon technologies is a major political challenge in which the risk of social acceptance plays an important role. Wójcik-Jurkiewicz et al. [1] studied the determinants of decarbonisation processes and from this perspective analysed the public perception of solutions that can be used to achieve the decarbonisation process. The main conclusion from the authors' work is that while decarbonisation is very necessary to protect the natural environment in Poland and people from diseases resulting from coal combustion, it cannot be achieved without changing public awareness. The entire decarbonisation process itself must be part of a broader sustainable energy strategy for Poland. First, campaigns are needed to change people's perceptions and expectations of government actions.
Pepliński and Czubak [16]	Cost-benefit analysis in the life cycle of lignite considering external costs associated with agriculture production in relation to the cone of depression.	Pepliński and Czubak [16] conducted a cost-benefit analysis of the life cycle of lignite and emphasised that in addition to externalities related to combustion and greenhouse gas emissions, externalities related to agriculture should also be taken into account in the context of the depression cone, i.e., costs that have a geological, agricultural, natural climate, and temporal and spatial dimension. More precisely, Pepliński and Czubak [16] proposed a method of calculating external costs associated with agricultural production, which they also demonstrated using the concrete example of open-cast lignite mining in Konin-Turek (estimation of external costs associated with crop production for the area of this open-cast mine). Their results show high externalities related to cereal and potato production (resulting from a decrease in yields) and no effect of the depression cone on sugar beet cultivation. Moreover, Pepliński and Czubak [16] emphasise that taking these costs into account would significantly worsen the profitability of lignite production.
Kasztelewicz et al. [22]	A study underpinning the strategic importance of lignite for Poland.	Kasztelewicz et al. [22] point to a number of factors underpinning the strategic importance of lignite for Poland, and in particular for regions such as Łódź and Bełchatów. The advantages of this fossil fuel resource include relatively large and recognised reserves, years of experience in the field, thanks to which Poland has very qualified technical, engineering and managerial staff, and very good scientific and technical support in the form of research institutes and scientific centres working closely with the mining industry, excellent technical support for the mining industry, and extensive cutting-edge technologies and machinery known worldwide.
Kasztelewicz et al. [26]	Analysis of the current and future situation of the lignite industry in Poland.	Kasztelewicz et al. [26] have shown possible development scenarios for lignite production in Poland until 2050. They refer in particular to the conditions of future use of this resource in the energy sector and in soil gasification. In their study, the authors pay great attention to the rich lignite deposits in Legnica and justify the need for their rational exploitation by strategic companies in the mining sector.
Nanaki et al. [29]	Analysis of the environmental impact of greenhouse gas emissions and other wastes generated by the extraction and transport of lignite in Greece.	Nanaki et al. [29] studied the environmental impact of greenhouse gas emissions and other wastes generated by the extraction and transportation of lignite in Greece. The study by Nanaki et al. [29] concludes that the technologies used would need to be replaced by more advanced technologies in order to achieve a significant reduction in GHG emissions, which could contribute to a reduction in emissions (i.e., NO_x, SO_2, and PM emissions) throughout the life cycle of lignite. Furthermore, Nanaki et al. [29] state that when looking at the problem more broadly, it is not the gas emissions that pose the greatest threat in the lignite life cycle, but the category of respiratory impacts and associated diseases [29].

Table A1. *Cont.*

Authors	Subject (What It Is Pertaining)/Area	Contribution/Details
Motyka et al. [46]	Analysis of the environmental changes caused by lignite mining in the Bełchatów mine.	Motyka et al. [46] studied the environmental changes caused by lignite mining in the Bełchatów mine. The authors emphasise that lignite mining requires intensive, deep drainage of groundwater from Quaternary, Tertiary and Cretaceous-Jurassic aquifers, resulting in the formation of a large cone of depression. At the time the authors conducted their study (i.e., in 2007), the area affected by the changed hydrodynamic conditions covered about 450 km^2, and the local lowering of the groundwater table reached even more than 250 m in some places. Lignite mining leads to significant geochemical processes (e.g., oxidation of sulphides or buffering of acid mine drainage) and altered hydrological conditions of the catchment in the area of the subsidence cone, which are responsible for a reduction of groundwater inflow into the watercourses. The authors emphasise that an anthropogenic, young aeration zone with oxygen access is formed under the conditions of groundwater lowering. The work of Motyka et al. [46] shows that mines such as "Bełchatów" carry out systematic monitoring of the hydrological environment, thanks to which it is possible to plan remediation scenarios.
Kittner et al. [85]	Investigation of air pollution risks from the combustion of lignite from Obilice in Kosovo. Analysis of trace metal content in lignite using inductively coupled plasma mass spectrometry (ICP-MS).	Kittner et al. [85] studied the risks of air pollution from the burning of lignite from Obilice in Kosovo (including the Trepca mine), the largest point source of air pollution in Europe. In their work, the authors used the method of inductively coupled plasma mass spectrometry (ICP-MS) to analyse the trace metal content in lignite from Obilice in Kosovo. The results of the study pointed to very significant air pollutants that resulted in trace metal contents in relation to the electricity generated, including As, Cr. Hg and Ni. The authors conclude that the energy strategy and the entire associated energy system should take health factors into account. In this context, the authors suggest developing other energy technologies that they believe would avoid many premature deaths.
Markandya and Wilkinson [35]	Assessment of health burdens/consequences for the use of different energy sources.	Markandya and Wilkinson [35] have summarised the state of knowledge on the health effects of using various fossil fuels and energy resources. The authors pay particular attention to the health effects and emphasise that these are greatest when using lignite sources. The article also addresses the need for carbon dioxide (CO_2) capture and storage to reduce CO_2 emissions from fossil fuel power plants. It points out that decreasing efficiency usually means using more primary fuel, although this is accompanied by an increase in certain waste products.
Oruc and Dincer [30]	Environmental impact assessment of various fossil fuels including lignite.	Oruc and Dincer [30] conducted an environmental impact assessment of various fossil fuels and other energy sources, including lignite. In their analysis, they considered the values of emission factors for carbon dioxide and carbon monoxide, nitrogen oxides and sulphur oxides. The analysis also considers how the impact of lignite drying techniques translates into improvements in these plant emission factors. The results of the study by Oruc and Dincer [30] show that the process of drying (in a drying chamber) and thus reducing the moisture content of the lignite does indeed contribute to a reduction in emissions of CO_2, NO_x and SO_2 from the combustion of lignite. The authors have carried out their calculations for a concrete example, namely for the Tuncbilek deposits.

Table A1. *Cont.*

Authors	Subject (What It Is Pertaining)/Area	Contribution/Details
Wang et al. [33]	A cost-benefit analysis of the life cycle of lignite in China (where lignite accounts for 13% of coal reserves), taking into account both economic costs and environmental impacts.	The authors conducted a life-cycle cost-benefit analysis of lignite, considering both the economic costs and environmental impacts of several key processes. The study also addressed the possibility of improving the economics of mining in terms of gains and losses within an integrated approach to life cycle assessment and life cycle costs (taking into account the application of new technologies such as lignite drying and densification). Among other things, the study identifies critical factors for reducing the environmental and economic impacts of lignite drying and densification technologies, which can be seen as an important contribution to policy-making regarding the extraction, processing and use of lignite resources.
Krümmelbein et al. [71]	Study on the recultivation of post-mining land in the region around the cities of Cottbus and Senftenberg in Lusatia, East Germany.	Kruemmelbein et al. [71] investigated the reclamation of post-mining land in the region around the cities of Cottbus and Senftenberg in Lusatia, East Germany. The aim of their work was to analyse how post-mining land can be recultivated into agricultural and forestry land. More specifically, the authors present the constraints and reclamation practices associated with the rehabilitation of Tertiary and Quaternary subsoils resulting from their natural composition and the technical processes of mining. The authors' analysis shows how the land can be used before and after mining and how the rehabilitated landscape can be used in the future. The study can be very useful in assessing the prospects for long-term rehabilitation of lignite mines.
Schreck [41]	Analysis of the negative environmental impacts of lignite mining by opencast lignite mines from the Leipzig, Halle and Bitterfeld region.	Schreck [41] has carried out an analysis of the negative environmental impacts of lignite mining by opencast lignite mines from the Leipzig, Halle and Bitterfeld region. The author describes and lists in great detail the negative impacts of mining activities, including changes in the landscape, impacts of mining activities on the environment, the devastation of large areas, the pollution of groundwater with pollutants dissolved in it, large industrial waste, residues of coal mining, highly toxic waste products from industrial plants in the analysed region. Other negative consequences of activities related to open pit mining are oxidation of mining wastes containing pyrite, acidification of soils and water bodies, and brines flowing into groundwater affecting the salinity of aquifers. The author has described all these consequences using examples from various case studies.
Singh and Sharma [86]	A method for separating lignite from impurities and other compounds/substances. The method increases the calorific value of lignite and benefits the environment.	In their study, Singh and Sharma [86] took up the issue of separating lignite from impurities and other compounds/substances. The aim of the study was to find a method that would increase the calorific value of lignite and provide environmental benefits. The study was carried out on a specific example, namely for lignite in Gurha block in Bikaner, Rajasthan. The main objective of lignite separation is to reduce ashes, sulphur and other mineral impurities in lignite to increase its calorific value and provide environmental benefits. The results of the analysis show that the most effective method for removing unwanted compounds/substances from lignite is separation through dense media using cumene and carbon tetrachloride, treating it in the size range from -10 mm to +4.75 mm. With this method, the calorific value of the lignite fuel can be significantly increased and the negative impact on the environment can be minimised.

Table A1. *Cont.*

Authors	Subject (What It Is Pertaining)/Area	Contribution/Details
Kermer et al. [58]	Analysis of the possibility of using by-products of lignite combustion as a source of various metals in industrial demand.	Kermer et al. [58] point out that the by-products of lignite combustion can be a potential source of many metals sought after by industry. Indeed, lignite combustion ash contains strategic metals, metalloids and rare earth elements (REEs). The study by Kermer et al. [58] seems to be very valuable as the authors have assessed the possibility of using this potential raw material for industrial purposes. The authors point out that such valuable pyrolytes, which are a source of metals sought after in industry, can be extracted in Germany in the Lausitz region. Furthermore, Kermer et al. [58] point out specific methods for the enrichment, separation and mobilisation of valuable materials from lignite ash. These methods include mechanical and thermal treatment as well as chemical and biological leaching. In thermally treated ashes, high extraction of metals such as Al, Ca, Fe, and Mg was achieved. Biological leaching with acidophilic microorganisms metabolising Fe/S (MO) and heterotrophic MO resulted in the equally high mobilisation of metals, e.g., for Al, Ca, Fe, Mg, Mn, V, Zn, Zr and for some REE. The authors' results indicate that the stabilised ash has good parameters and can be used e.g., as an additive in cement and concrete production.
Singh and Singh [87]	A study of the potential for improving the calorific value of lignite and the use of its by-products.	Singh and Singh [87] conducted a study to identify a method for improving the calorific value of lignite and the use of its by-products for the manufacture of cement, roof tiles and bricks. The method described by the authors is separation (wet screening) using the natural ability of the mineral to dissolve itself in water, followed by wet screening and separation of the +1 mm fraction.
Kasztelewicz et al. [88]	Analysis of the lignite industry in Poland, focusing on the benefits of this type of fossil fuel for domestic energy production.	Kasztelewicz et al. [88] have done a very comprehensive analysis of the lignite industry, focusing on the benefits of this type of fossil fuel for domestic energy production. Among other things, the authors highlight the historical conditions that favour lignite and the possibilities to use it outside the energy sector (e.g., as an additive in the production of fertilisers). The authors point out that this type of energy accounts for about 35% of energy production in Poland and energy complexes based on lignite (e.g., the Bełchatów described in this paper) are a guarantee of Poland's energy security. An important argument in favour of lignite is its relative price stability (on the commodity markets) compared to other energy sources such as oil, natural gas or hard coal. The authors also highlight other important aspects of lignite mining, such as the fact that energy complexes based on this energy source have so far been profitable and have generated surpluses that enable the financing of maintenance and development investments in other segments of the energy industry as well. It is also important to note that lignite-fired power plants do not need or receive public support in the form of subsidies or tax breaks. In this context, the work of Kasztelewicz et al. [88] is a confirmation of our findings, which are the subject of this article. The authors present perspectives for the optimal use of lignite deposits in the Konin and Złoczew area, as well as deposits in Gubin and Legnica and in the Rawicz (Oczkowice) region, and emphasise that these deposits could eventually replace the current active mining and power basins, enabling Poland to obtain cheap and clean electricity based on the latest solutions in the field of clean energy technologies.

Table A1. *Cont.*

Authors	Subject (What It Is Pertaining)/Area	Contribution/Details
Terminski [45]	Assessment of Mining Induced Displacement and Resettlement (MIDR).	Terminski [45] examined displacement and resettlement caused by mining activities, which is a very diverse global socio-economic problem affecting regions with mining production. The author highlights the importance of the loss or significant restriction of access to basic material and immaterial resources, mentioning, among other things, the loss of access to land, pasture, forests and clean water, as well as the loss of socio-economic ties. The author refers to the historical context of displacement caused by mining activities and emphasises that it is a global problem. The problem is significant in China and India, among others, but also in African and European countries (the author mentions Poland and Germany as the two European countries most affected by resettlement).
Henselowsky et al. [48]	Quantitative assessment of mining-induced changes in the terrain relief in the Rhenish lignite mining area in Germany.	Henselowsky et al. [48] quantitatively assessed the changes in the terrain relief caused by mining in one of the oldest and currently largest lignite mining areas in Europe, the Rhenish lignite mining area in Germany. The authors developed a historical digital elevation model that enabled them to quantitatively assess relief changes in comparison to elevation data from different time periods, i.e., from the year 2000 and from 2015. They used maps from the first geodetic mapping of 1893 as a starting point. The results of their study show that almost half of the study area (184 km^2) is characterised by some relief deficit and about 15% has positive relief differences.

Source: own elaboration.

References

1. Wójcik-Jurkiewicz, M.; Czarnecka, M.; Kinelski, G.; Sadowska, B.; Bilińska-Reformat, K. Determinants of Decarbonisation in the Transformation of the Energy Sector: The Case of Poland. *Energies* **2021**, *14*, 1217. [CrossRef]
2. Jonek-Kowalska, I. Transformation of energy balances with dominant coal consumption in European economies and Turkey in the years 1990–2017. *Oeconomia Copernic.* **2019**, *10*, 627–647. [CrossRef]
3. Markandya, A.; Arto, I.; González-Eguino, M.; Román, M.V. Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union. *Appl. Energy* **2016**, *179*, 1342–1350. [CrossRef]
4. Victoria, M.; Zhu, K.; Brown, T.; Andresen, G.B.; Greiner, M. Early Decarbonisation of the European Energy System Pays Off. *SSRN Electron. J.* **2020**, *11*, 6223.
5. Tajduś, A.; Dubiński, J. Globalne problemy górnictwa węgla brunatnego. *Górnictwo Geoinżynieria* **2011**, *35*, 367–379.
6. Knobloch, F.; Pollitt, H.; Chewpreecha, U.; Daioglou, V.; Mercure, J.F. Simulating the Deep Decarbonisation of Residential Heating for Limiting Global Warming to 1.5 °C. *Energy Effic.* **2019**, *12*, 521–550. [CrossRef]
7. Pavloudakis, F.; Roumpos, C.; Karlopoulos, E.; Koukouzas, N. Sustainable rehabilitation of surface coal mining areas: The case of Greek lignite mines. *Energies* **2020**, *13*, 3995. [CrossRef]
8. Alves Dias, P.; Kanellopoulos, K.; Medarac, H.; Kapetaki, Z.; Miranda-Barbosa, E.; Shortall, R.; Tzimas, E. *EU Coal Regions: Opportunities and Challenges Ahead*; European Commission, Joint Research Centre: Petten, The Netherlands, 2018; pp. 20–32.
9. Widera, M.; Kasztelewicz, Z.; Ptak, M. Lignite mining and electricity generation in Poland: The current state and future prospects. *Energy Policy* **2016**, *92*, 151–157. [CrossRef]
10. Projekt Ustawy o Zmianie Ustawy—Prawo Geologiczne i Górnicze z 2019 r. (Druk nr 3818). Available online: http://orka.sejm.gov.pl/Druki8ka.nsf/0/1F0301E29B58FBB2C12584710062E470/%24File/3818.pdf (accessed on 25 February 2022).
11. Nie dla Odkrywki Złoczew! Mieszkańcy Nie Chcą Nowych Kopalni Węgla w Polsce. Protesty Przeciwko Specustawie Węglowej. Available online: https://polskatimes.pl/nie-dla-odkrywki-zloczew-mieszkancy-nie-chca-nowych-kopalni-wegla-w-polsce-protesty-przeciwko-specustawie-weglowej/ar/c3-14510071 (accessed on 15 February 2022).
12. Jest Porozumienie z Rządem w Sprawie Transformacji Górnictwa. Available online: http://solidarnosckatowice.pl/pl-PL/jest_porozumienie_z_rzadem_w_sprawie_transformacji_gornictwa.html (accessed on 15 February 2022).
13. Chmielewski, A. Nuclear Power for Poland. *World J. Nucl. Sci. Technol.* **2013**, *3*, 123–130. [CrossRef]
14. Arora, V.K.; Scinocca, J.F.; Boer, G.J.; Christian, J.R.; Denman, K.L.; Flato, G.M.; Merryfield, W.J. Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases. *Geophys. Res. Lett.* **2011**, *38*, 1–6. [CrossRef]
15. Manne, A.S.; Richels, R.G. CO_2 Emission Limits: An Economic Cost Analysis for the USA. *Energy J.* **1990**, *11*, 51–74. [CrossRef]
16. Pepliński, B.; Czubak, W. The influence of opencast lignite mining dehydration on plant production—A methodological study. *Energies* **2021**, *14*, 1917. [CrossRef]
17. Kasztelewicz, Z. *Rekultywacja Terenów Pogórniczych w Polskich Kopalniach Odrywkowych*; AGH: Cracow, Poland, 2010.

18. Kozłowski, Z. Present situation and prospects for lignite in the Polish power-generation industry. *Appl. Energy* **2003**, *74*, 323–329. [CrossRef]
19. Blaschke, W.S.; Gawlik, L. Energy supply policies in Poland: Present and future. In *Mining in the New Millennium Challenges and Opportunities*; Golosiński, T.S., Ed.; CRC Press: Boca Raton, FL, USA, 2020; pp. 225–229.
20. Schulz, S.; Schwartzkopff, J. *G7 Coal Phase Out: Germany: A Review for Oxfam*; E3G: London, UK, 2017; pp. 4–23.
21. Iatco, C.; Bostan, I.; Lazar, C.; Burciu, A. Reconsidering Economic Coal Resources in Drafting Energy Strategies. The case of Romania. *Environ. Eng. Manag. J.* **2013**, *12*, 2025–2030. [CrossRef]
22. Kasztelewicz, Z.; Tajduś, A.; Ptak, M. Czy legnicki węgiel brunatny to skarb czy przekleństwo dla tej ziemi? cz. 1. In Proceedings of the Conference Przestrzenne, Środowiskowe i Techniczne Uwarunkowania Zagospodarowania Złoża Węgla Brunatnego "LEGNICA", Legnica, Poland, 28 October 2016.
23. Kasztelewicz, Z.; Ptak, M. Condition of the mining and energy sectors based on brown coal and conditionings of their development in Poland. *Gospod. Surowcami Miner.* **2009**, *25*, 137–151.
24. Jonek-Kowalska, I. Coal mining in Central-East Europe in perspective of industrial risk. *Oeconomia Copernic.* **2017**, *8*, 131–143. [CrossRef]
25. Radecki, G. Kopalnia jako miejsce wykonywania pracy górniczej uprawniającej do emerytury górniczej. *Prawne Probl. Górnictwa Ochr. Środowiska* **2017**, *2*, 59–77.
26. Kasztelewicz, Z.; Tajduś, A.; Ptak, M. Legnicki węgiel brunatny to skarb czy przekleństwo dla tej Ziemi? cz. II. *Przegląd Tech. Gaz. Inżynierska* **2017**, *11–12*, 11–15.
27. Dymitrowicz, J.; (Bełchatów Lignite Mine Investors Relations Department, Bełchatów, Poland). Personal Communication, 2020.
28. Chadwick, M.J.; Highton, N.H.; Lindman, N. *Environmental Impacts of Coal Mining & Utilization: A Complete Revision of Environmental Implications of Expanded Coal Utilization*; Pergamon Press: New York, NY, USA, 1987.
29. Nanaki, E.A.; Koroneos, C.J.; Xydis, G.A. Environmental impact assessment of electricity production from lignite. *Environ. Prog. Sustain. Energy* **2016**, *35*, 1868–1875. [CrossRef]
30. Oruc, O.; Dincer, I. Environmental impact assessment of using various fuels in a thermal power plant. *Int. J. Glob. Warm.* **2019**, *18*, 191–205. [CrossRef]
31. Bielowicz, B. Występowanie wybranych pierwiastków szkodliwych w polskim węglu brunatnym. *Gospod. Surowcami Miner.* **2013**, *29*, 47–59. [CrossRef]
32. Gesundheit: Feiner Staub, Großer Schaden. Available online: https://www.boell.de/de/2015/06/02/gesundheit-feiner-staub-grosser-schaden (accessed on 30 May 2022).
33. Wang, Q.; Liu, W.; Yuan, X.; Zheng, X.; Zuo, J. Future of lignite resources: A life cycle analysis. *Environ. Sci. Pollut. Res.* **2016**, *23*, 24796–24807. [CrossRef] [PubMed]
34. Lignite Coal—Health Effects and Recommendations from the Health Sector. Available online: https://www.env-health.org/wp-content/uploads/2018/12/HEAL-Lignite-Briefing-en_web.pdf (accessed on 30 May 2022).
35. Markandya, A.; Wilkinson, P. Electricity generation and health. *Lancet* **2007**, *370*, 979–990. [CrossRef]
36. Bełchatów Lignite Mine; (Investors Relations Department, Bełchatów, Poland). Personal Communication, 2021.
37. Kubiczek, K. *Lignite—What is the Future? Is the Development of Opencast Lignite Mines a Future for the Energy Industry or Rather an Environmental Problem and a Violation of Basic Human Rights?* Ecological Association EKO-UNIA: Wrocław, Poland, 2017.
38. Markewitz, P.; Robinius, M.; Stolten, D. The Future of Fossil Fired Power Plants in Germany—A Lifetime Analysis. *Energies* **2018**, *11*, 1616. [CrossRef]
39. Jakob, M.; Steckel, J.C.; Jotzo, F. The future of coal in a carbon-constrained climate. *Nat. Clim. Chang.* **2020**, *10*, 704–707. [CrossRef]
40. Zipper, C.; Burger, J.; Skousen, J.; Angel, P.; Barton, C.; Davis, V.; Franklin, J. Restoring forests and associated ecosystem services on Appalachian coal surface mines. *Environ. Manag.* **2011**, *47*, 751–765. [CrossRef]
41. Schreck, P. Environmental impact of uncontrolled waste disposal in mining and industrial areas in Central Germany. *Environ. Geol.* **1998**, *35*, 66–72. [CrossRef]
42. Karczewska, A. *Ochrona Gleb i Rekultywacja Terenów Zdegradowanych*; Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu: Wrocław, Poland, 2012.
43. Griazev, M.V.; Kachurin, N.M.; Spirin, V.I. Energy-efficient technologies of integrated coal and mining waste development in the Moscow Coal Basin in the context of secure and sustainable supply of row materials in Central Russia. *Eurasian Min.* **2016**, *2*, 15–19. [CrossRef]
44. Vassilis, M.; Theodoros, T.; Spyridon, P.; Panagiotis, T.; Alexandros, C.; Konstantinos, V. Large induced displacements and slides around an open pit lignite mine, Ptolemais Basin, Northern Greece. In *Engineering Geology for Society and Territory—Volume 2*; Springer: Cham, Germany, 2015; pp. 311–315.
45. Terminski, B. Mining-induced displacement and resettlement: Social problem and human rights issue (a global perspective). *SSRN Electron. J.* **2012**, *2028490*, 1–45. [CrossRef]
46. Motyka, J.; Czop, M.; Jończyk, W.; Stachowicz, Z.; Jończyk, I.; Martyniak, R. Wpływ głębokiej eksploatacji węgla brunatnego na zmiany środowiska wodnego w rejonie Kopalni "Bełchatów". *Górnictwo I Geoinżynieria* **2007**, *31*, 477–487.
47. Sloss, L. *Environmental and Other Effects of Mining and Transport. Technical Report No CCC/281*; IEA Clean Coal Centre: London, UK, 2017.

48. Henselowsky, F.; Rölkens, J.; Kelterbaum, D.; Bubenzer, O. Anthropogenic relief changes in a long-lasting lignite mining area ('Ville', Germany) derived from historic maps and digital elevation models. *Earth Surf. Process. Landf.* **2021**, *46*, 1725–1738. [CrossRef]
49. Raab, A.; Raab, T.; Takla, M.; Nicolay, A.; Müller, F.; Rösler, H.; Bönisch, E. Reconstructing past environments and societies-interdisciplinary research in the open cast mine Jänschwalde, Germany. In Proceedings of the Conference EGU General Assembly 2013, Vienna, Austria, 22–27 April 2012.
50. Monjezi, M.; Shahriar, K.; Dehghani, H. Environmental impact assessment of open pit mining in Iran. *Environ. Geol.* **2009**, *58l*, 205–216. [CrossRef]
51. Ghose, M.K.; Majee, S.R. Assessment of the impact on the air environment due to opencast coal mining—An Indian case study. *Atmos. Environ.* **2000**, *34*, 2791–2796. [CrossRef]
52. Kasztelewicz, Z.; Zajączkowski, M. Wpływ działalności górnictwa węgla brunatnego na sektor publiczny. *Górnictwo I Geoinżynieria* **2010**, *4*, 327–338.
53. Pazderski, L.; Bandera, J. Społeczności lokalne wobec węgla brunatnego: Dlaczego perspektywa wpływów finansowych do budżetów gmin i nowych miejsc pracy bywa niewystarczająca. In Proceedings of the XXXI Conference on Energy Resources and Energy in the National Economy, Zakopane, Poland, 15–18 October 2017.
54. Rolfe, J.; Williams, G.; Lockie, S. *Assessing the Social and Economic Impacts of Coal Mining on Communities in the Bowen Basin: Summary and Recommendations*; Australian Coal Association Research Program (ACARP): Rockhampton, Australia, 2005.
55. Shongwe, B. The Impact of Coal Mining on the Environment and Community Quality of Life: A Case Study Investigation of the Impacts and Conflicts Associated with Coal Mining in the Mpumalanga Province, South Africa. Master Thesis, University of Cape Town, Cape Town, South Africa, 2018.
56. Kleszczów Municipality; (Investors Relations Department, Kleszczów, Poland). Personal Communication, 2021.
57. Maciejewska, A. *Węgiel Brunatny Jako Źródło Substancji Organicznej i Jego Wpływ na Właściwości Gleb*; Oficyna Wydawnicza Politechniki Warszawskiej: Warsaw, Poland, 1998.
58. Kermer, R.; Hedrich, S.; Bellenberg, S.; Brett, B.; Schrader, D.; Schoenherr, P.; Janneck, E. Lignite ash: Waste material or potential resource-Investigation of metal recovery and utilization options. *Hydrometallurgy* **2017**, *168*, 141–152. [CrossRef]
59. Sala, K. Impact of Industry on the Socio-Economic Situation and Natural Environment of the Kleszczów Commune (Poland). *Stud. Ind. Geogr. Comm. Pol. Geogr. Soc.* **2019**, *33*, 143–152.
60. Jaros, J. *Zarys Dziejów Górnictwa Węglowego*; Wydawnictwo Naukowe PWN: Warsaw, Poland, 1975.
61. Wachowiak, G.; Galiniak, G.; Jończyk, W.; Martyniak, R. Ocena zmian odpływu w zlewni rzeki Widawki w roku hydrologicznym 2010 pod wpływem oddziaływania inwestycji górniczo-energetycznej w rejonie Bełchatowa. *Górnictwo Geoinżynieria* **2011**, *35*, 381–395.
62. Grycuk, A. Centra nowoczesnych usług biznesowych w Polsce. *Infos Zagadnienia Społeczno-Gospod.* **2014**, *3*, 1–4.
63. Greinert, A. Węgiel brunatny—Czy będzie polskim surowcem energetycznym XXI wieku? *Zesz. Naukowe. Inżynieria Sr.* **2014**, *154*, 87–102.
64. Chwastek, J.; Dudek, Z.; Targosz, A. Land reclamation trends in Bełchatów-Szczerców. *Ochr. Teren. Gor.* **1987**, *21*, 9–17.
65. Kasztelewicz, Z.; Kaczorowski, J. Rekultywacja i rewitalizacja kopalń węgla brunatnego na przykładzie Kopalni "Bełchatów". *Górnictwo Geoinżynieria* **2009**, *33*, 187–212.
66. Mocek-Płóciniak, A. Reclamation and Development of Geomechanically Transformed Land in the Konin-Turek Coal Basin. *Pol. J. Soil Sci.* **2016**, *49*, 123–132. [CrossRef]
67. Gilewska, M.; Otremba, K. Rekultywacja i rewitalizacja gruntów pogórniczych na przykładzie gminy Kleczew. *Zesz. Naukowe. Inżynieria Sr.* **2015**, *159*, 15–21.
68. Metelski, D.; Mihi-Ramirez, A. The economic impact of remittances and foreign trade on migration. Granger-Causality approach. *Eng. Econ.* **2015**, *26*, 364–372. [CrossRef]
69. Metelski, D. *La Migración Económica Internacional y las Variables Económicas*; Universidad de Granada: Granada, Spain, 2016.
70. Sobieraj, J.; Metelski, D. Governments' Responses to COVID-19 and the Implications of the Governance and Control of the Pandemic. *SSRN Electron. J.* **2020**, *3707251*, 1–50. [CrossRef]
71. Krümmelbein, J.; Bens, O.; Raab, T.; Anne Naeth, M. A history of lignite coal mining and reclamation practices in Lusatia, eastern Germany. *Can. J. Soil Sci.* **2012**, *92*, 53–66. [CrossRef]
72. Sobieraj, J.; Bryx, M.; Metelski, D. Stormwater Management in the City of Warsaw: A Review and Evaluation of Technical Solutions and Strategies to Improve the Capacity of the Combined Sewer System. *Water* **2022**, *14*, 2109. [CrossRef]
73. Zawadzki, J.; Fabijańczyk, P.; Przeździecki, K. Geostatistical Methods as a Tool Supporting Revitalization of Industrially Degraded and Post-Mining Areas. *New Trends Prod. Eng.* **2020**, *3*, 30–40. [CrossRef]
74. Przeździecki, K.; Zawadzki, J.; Miatkowski, Z. Use of the temperature–vegetation dryness index for remote sensing grassland moisture conditions in the vicinity of a lignite open-cast mine. *Environ. Earth Sci.* **2018**, *77*, 623. [CrossRef]
75. D'Emilio, M.; Coluzzi, R.; Macchiato, M.; Imbrenda, V.; Ragosta, M.; Sabia, S.; Simoniello, T. Satellite data and soil magnetic susceptibility measurements for heavy metals monitoring: Findings from Agri Valley (Southern Italy). *Environ. Earth Sci.* **2018**, *77*, 63. [CrossRef]
76. Mutanga, O.; Kumar, L. Google earth engine applications. *Remote Sens.* **2019**, *11*, 591. [CrossRef]

77. Kennedy, R.E.; Yang, Z.; Gorelick, N.; Braaten, J.; Cavalcante, L.; Cohen, W.B.; Healey, S. Implementation of the LandTrendr algorithm on google earth engine. *Remote Sens.* **2018**, *10*, 691. [CrossRef]
78. Zawadzki, J.; Cieszewski, C.J.; Zasada, M.; Lowe, R.C. Applying geostatistics for investigations of forest ecosystems using remote sensing imagery. *Silva Fenn.* **2005**, *39*, 599–618. [CrossRef]
79. Zawadzki, J. Wykorzystanie metod geostatycznych w badaniach środowiska przyrodniczego. *Pr. Nauk. Politech. Warsz. Inżynieria Sr.* **2005**, *49*, 3–13.
80. Zawadzki, J.; Przeździecki, K.; Miatkowski, Z. Determining the area of influence of depression cone in the vicinity of lignite mine by means of triangle method and LANDSAT TM/ETM satellite images. *J. Environ. Manag.* **2015**, *166*, 605–614. [CrossRef]
81. UM Kleszczów. Kopalnia Węgla Brunatnego Szansą Rozwoju Regionu Opublikowanej Przez UM Kleszczów. Available online: https://slideplayer.pl/slide/824762/ (accessed on 8 June 2022).
82. Kleszczów Municipal Council. Założenia do Planu Zaopatrzenia w Ciepło, Energię Elektryczną i Paliwa Gazowe dla Obszaru Gminy Kleszczów na Lata 2019–2034. Available online: https://www.bip.kleszczow.pl/res/serwisy/pliki/24615677?version=1.0 (accessed on 8 June 2022).
83. Tkacz, K. Rewitalizacja terenów KWB "Bełchatów" jako szansa na rozwój małych miast. *Przestrz. Forma* **2015**, *23*, 267–278.
84. Maciejewska, A. *Rekultywacja i Ochrona Środowiska w Górnictwie Odkrywkowym*; Oficyna Wydawnicza Politechniki Warszawskiej: Warsaw, Poland, 2000.
85. Kittner, N.; Fadadu, R.P.; Buckley, H.L.; Schwarzman, M.R.; Kammen, D.M. Trace metal content of coal exacerbates air-pollution-related health risks: The case of lignite coal in Kosovo. *Environ. Sci. Technol.* **2018**, *52*, 2359–2367. [CrossRef] [PubMed]
86. Singh, A.V.; Sharma, N.K. Application of dense media separation for beneficiation of lignite mining waste into combustible fuel. *Energy Sources Part A Recovery Util. Environ. Eff.* **2015**, *37*, 1821–1827. [CrossRef]
87. Singh, A.V.; Singh, R. Separation of energy-rich fractions from lignite mining waste using the wet sieving technique. *Energy Sources Part A Recovery Util. Environ. Eff.* **2015**, *37*, 1520–1525. [CrossRef]
88. Kasztelewicz, Z.; Ptak, M.; Sikora, M. Węgiel brunatny optymalnym surowcem energetycznym dla Polski. *Zesz. Nauk. Inst. Gospod. Surowcami Miner. Energią PAN* **2018**, *106*, 61–83.